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Real-Time Meteorological Battlespace Characterization in Support of Sea Power 21

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14. ABSTRACT
This report presents our findings from a three-year Rapid Transition Project (RTP) designed to develop and test a new environmental assessment concept in coordination with the Naval Pacific Meteorology and Oceanography Detachment, Fallon, NV, in support of the Naval Strike and Air Warfare Center (NSAWC). This project leverages the current operational on-demand atmospheric mesoscale modeling system to provide the core component for an extended capability called "Nowcast" that extracts and fuses the available multi-source sensor data and then shares the resulting common representation of the relevant environmental information as web-enabled products using standards-based, net-centric techniques appropriate for future military networks and operations. The groundwork for development of the Navy Nowcast capability began in 1998 when a forward-deployed mesoscale data analysis and forecast system, using a forerunner of the Coupled Ocean/Atmosphere Mesoscale Prediction–On Scene (COAMPS-OS®) system, was established at the Naval Meteorology and Oceanography (METOC) Centers worldwide. A year later, after informal consultation with end users, the Nowcast architecture, design elements, and communication requirements were documented (see Appendix), and development of a prototype system was begun. In 2002, an operational prototype was implemented at the Naval Pacific Meteorology and Oceanography Center–San Diego (NPMOC-SD), in support of the Joint Task Force Commander during Fleet Battle Experiment Juliet (FBE-J), a component of the larger U.S. Joint Forces Command Millennium Challenge 02 (MC02) experiment, in which live and simulated exercises were used to evaluate technological innovations. Positive reports from users indicated that Nowcast products provided remote users with unprecedented access to radar reflectivity (thunderstorm), cloud cover, and high-resolution surface wind products, at up to a 5-minute refresh rate. The high-resolution Nowcast and COAMPS-OS products filled voids left by sparse, irregular, and previously unassimilated observations throughout the battlespace. The system was then applied to support strike warfare training at Fallon and this is the resulting final report.

15. SUBJECT TERMS
Nowcast, Data fusion, Data assimilation, Meteorology, Aviation, Weather, Battlespace environment

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1. INTRODUCTION

In 2003 the U.S. Navy launched the Sea Power 21 transformation initiative to provide revolutionary information superiority and networked force capabilities in order to deliver improved operational efficiency and independence to Joint Force Commanders. The three pillars of Sea Power 21 are: Sea Strike - the ability to project offensive power; Sea Shield - the extension of defensive assurance; and Sea Basing – an enhanced operational independence for Joint Forces. In Sea Power 21, Sea Strike, Sea Shield, and Sea Basing are enabled by ForceNet, an overarching effort to integrate sensors, platforms, weapon systems, command and control systems, and war-fighters into a fully network-enabled combat force that can apply net-centric principles to maintain enhanced situational awareness and thus a decisive advantage over adversaries.

Current military operations, however, have limited capabilities to assess and maintain an up-to-date common situational awareness of the environmental battlespace. This lack of comprehensive weather intelligence results in increased risk to the warfighter, adverse mission impact and missed targets, and perhaps significant financial and opportunity loss from unexpended weapons and targets not prosecuted. This project leverages the current operational on-demand atmospheric mesoscale modeling system to provide the core component for an extended capability called "Nowcast" that extracts and fuses the available multi-source sensor data and then shares the resulting common representation of the relevant environmental information as web-enabled products using standards-based, net-centric techniques appropriate for ForceNet.

The groundwork for development of the Navy Nowcast capability began in 1998 when forward-deployed mesoscale data analysis and forecast system, using a forerunner of the Coupled Ocean/Atmosphere Mesoscale Prediction System – On Scene (COAMPS-OS®) system, was established at the Naval Meteorology and Oceanography (METOC) Centers world-wide. A year later, after informal consultation with end users, the Nowcast architecture, design elements, and communication requirements were documented, and development of a prototype system was begun (Appendix). In 2002, the operational prototype was implemented at the Naval Pacific Meteorology and Oceanography Center – San Diego (NPMOC-SD), in support of the Joint Task Force Commander during Fleet Battle Experiment Juliet (FBE-J), a component of the larger U.S. Joint Forces Command Millennium Challenge 02 (MC02) experiment, in which live and simulated exercises were used to evaluate recent technological innovations (Strahl et al. 2003; Geiszler et al. 2003). Positive reports from users indicated that Nowcast products provided remote users with unprecedented access to radar reflectivity (thunderstorm), cloud cover, and high-resolution surface wind products, at up to a 5-minute refresh rate. The high-resolution Nowcast and COAMPS-OS products filled voids left by sparse, irregular, and previously unassimilated observations throughout the battlespace.

Manuscript approved August 1, 2007.

2. OBJECTIVE

This Rapid Transition Project (RTP) is a coordinated effort with Naval Strike and Air Warfare Center (NSAWC), and the Navy Pacific Meteorology and Oceanography Detachment (NPMOD) at the Naval Air Station (NAS) Fallon, NV, to create a shore test and development site for Nowcast in order to provide and evaluate enhanced weather support to strike warfare (STW). This three-year demonstration (FY 2004 – FY 2006) of real-time automated nowcast and forecast products for Fallon has provided additional support to NPMOD Fallon for STW training beyond the support traditionally provided. Comments from Warfighters (pilots, squadron commanders, air traffic control specialists, STW planners, and operational METOC specialists) within a focused Integrated Product Team (IPT) provided valuable feedback to improve the automated system; verification and validation data collected has helped to scientifically evaluate the value added by Nowcast to traditional human-intensive STW forecasting techniques.

Another aspect of this project is to use the prototype Nowcast system to develop, test, and evaluate other, non-traditional sources of environmental data. Because of the lack of dedicated sensors, the METOC community has championed the concept of “through-the-sensor” (TTS) technology, where tactical data that are collected for intelligence and surveillance reasons are processed in parallel for environmental information. Here, we focused on Doppler radar data and aircraft data from unmanned aerial vehicle (UAV) systems. Although not an objective for this project, it is anticipated that Tactical Decision Aids (TDAs), when coupled to updated environmental nowcast databases, will provide enhanced operational capabilities due to the higher (than normally provided) spatial and temporal resolution of the environmental situational awareness information.

3. APPROACH

COAMPS-OS and Nowcast are the two components of the RTP that collect, process, quality control, extract, fuse and assimilate sensor data from various platforms and predict the near-term atmospheric conditions. They have been integrated into a small 22-processor LINUX cluster computer system installed at NRL Monterey with unclassified network access provided to NPMOD Fallon and NSAWC in a reach-back mode of operation. Although NSAWC is located at Fallon in large part because of the high percentage of “good days for flying” weather, the area does experience hazardous and challenging weather: winter storms and related flight icing conditions, summer thunderstorms, cloud ceiling and visibility restrictions, strong surface winds, including blowing dust which varies from valley to valley. Despite the typically good weather, Nowcast was implemented where the war-fighter trains, as a means of exposing a capability that may eventually transition to operations. The strategy was to introduce war-fighters to advanced R&D capabilities while “fine-tuning” Nowcast development by working with NPMOD Fallon and NSAWC.

To provide data for the nowcast/forecast system, a LINUX version of the Tactical Environmental Database System (TEDS) was installed with a real-time data feed of global model grids and conventional observations from FNMOC. A real-time data

interface was developed for the local Supplemental Weather Radar (SWR), operated by NPMOD Fallon. The SWR is an Enterprise Inc. C-band Doppler weather radar implemented by SPAWAR. We integrated full-volume, full-resolution SWR data with separate data feeds of NOAA Weather Surveillance Radar- 88 Doppler (WSR-88D) Level II and Level III data available from 13 sites in the area surrounding the Fallon Range Training Complex. This LINUX system was originally planned for SIPRNET implementation at NRL, however, the Trusted Gateway System (TGS) necessary to provide the unclassified-to-classified data transfer capability was not completed inside the RTP time frame.

To supplement data provided by the radars and FNMOC, the Desert Research Institute (DRI) was contracted to design, purchase, and install four surface sensor suites to provide a small, local sensor network over the Fallon ranges. The automated surface observations provide verification data for Nowcast products and help improve NPMOD Fallon's awareness of conditions out in the range, where complex terrain influences the wind flow and mesoscale variations in thunderstorms and winter storms make accurate forecasting and assessment of "weather on target" difficult. Although the sensor network was designed to provide observations in near real-time, we were not able to achieve this goal without cooperation from the Fallon Range communications. DRI was, however, able to provide the data approximately one-hour late via a geostationary satellite communications pathway that was already established.

4. WORK COMPLETED

4.1 DATA ACQUISITION

4.1.1 COAMPS® High Resolution Modeling

COAMPS-OS was used to configure and run a multi-nested 36-hr COAMPS forecast executed twice a day at 00Z and 12Z. The domain is shown in Figure 1 with the coarse nest a 61 X 61 grid at 54 km spacing, the second nest a 73 X 73 grid with 18 km spacing, the third nest a 103 X 103 grid with 6 km spacing, and the innermost nest a 133 X 121 grid with 2 km spacing. COAMPS was run in a 12 hr data assimilation cycle with the previous 12 hr forecast serving as the background fields for the subsequent analysis, performed independently at each cycle, for each nest. Each forecast cycle required approximately seven hours of wall time for computation and produced approximately 43,000 individual forecast grid fields. Default forecast map products shown in Table 1 were routinely and automatically produced each forecast hour for each nest and posted to the COAMPS-OS web site. In addition, the custom profile products for the locations listed in Table 2 were produced after consulting with NPMOD Fallon and these were also updated automatically on the web site while COAMPS was running. One novel feature of this COAMPS setup was the high vertical resolution grid – Table 3 lists the height of the midpoint and thickness of each of the 43 vertical sigma levels (COAMPS uses a terrain following sigma-z vertical coordinate system); the upper boundary of the model domain is 34800 m. This vertical grid was developed to provide close to 1000 ft vertical resolution for the cloud cross section products described in Section 4.3.

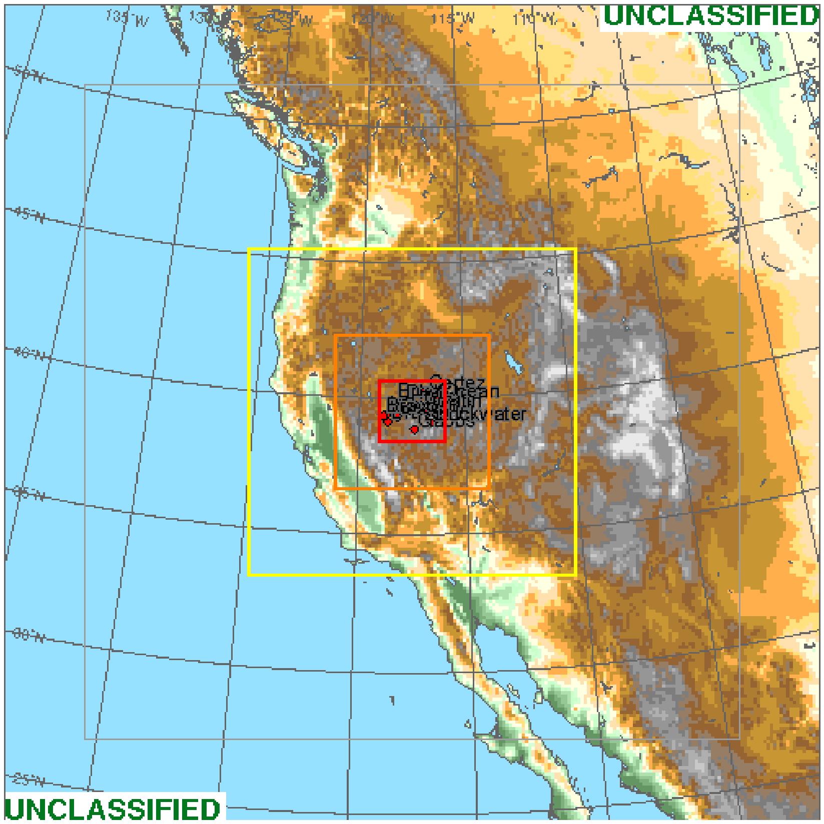

Fig. 1. The COAMPS computational domain that covers the Fallon Range Training Complex. The four nests telescope from 54, 18, 6, to 2 km grid spacing. The labels within the innermost nest refer to point locations where meteogram and skew-T profile forecast products are produced. The light grey line within the outermost coarse nest shows the interpolation boundary of the global lateral boundary conditions.

Table 1. List of default forecast map products produced by COAMPS-OS for each nest.

1	2 m Air Temperature, 10 m Winds, Sea Level Pressure
2	10 m Wind Speed and Streamlines
3	250 mb Winds
4	500 mb Heights, Winds, Vorticity
5	700 mb Heights, Vertical Velocity
6	850 mb Heights, Air Temperature, Winds
7	925 mb Heights, Winds, Relative Humidity
8	Sea Level Pressure, Accumulated Precipitation
9	Sea Level Pressure, 1000-500 mb Thickness, Surface Temperature
10	Cloud Ceiling Height
11	Hourly Precipitation
12	Jet Stream
13	Model-predicted Radar Reflectivity

Table 2. List of locations and positions for custom forecast products produced by COAMPS-OS for the Fallon domain. Positions are the nearest grid point to the requested location.

1	Austin	Lat: 39.55 N, Lon: 116.95 W
2	Bravo 16	Lat: 39.34 N, Lon: 118.84 W
3	Bravo 17	Lat: 39.31 N, Lon: 118.22 W
4	Bravo 19	Lat: 39.14 N, Lon: 118.67 W
5	Bravo 20	Lat: 39.90 N, Lon: 118.39 W
6	Cortez	Lat: 40.26 N, Lon: 116.89 W
7	Dixie	Lat: 39.85 N, Lon: 118.01 W
8	Duckwater	Lat: 39.11 N, Lon: 116.59 W
9	EW-71	Lat: 39.54 N, Lon: 117.74 W
10	Gabbs	Lat: 38.85 N, Lon: 117.40 W
11	KNFL	Lat: 39.44 N, Lon: 118.70 W
12	Diamond	Lat: 39.90 N, Lon: 116.24 W

Table 3. List of COAMPS output sigma levels (m) and the thickness (m) of each sigma layer for the Fallon domain.

Index	Output Level	Layer Thickness		Index	Output Level	Layer Thickness
1	31050	7500		23	4350	300
2	24400	5800		24	4050	300
3	19400	4200		25	3750	300
4	16050	2500		26	3450	300
5	14300	1000		27	3150	300
6	13300	1000		28	2850	300
7	12425	750		29	2550	300
8	11675	750		30	2250	300
9	10925	750		31	1950	300
10	10175	750		32	1650	300
11	9425	750		33	1350	300
12	8675	750		34	1050	300
13	8050	500		35	750	300
14	7550	500		36	500	200
15	7050	500		37	330	140
16	6550	500		38	215	90
17	6150	300		39	140	60
18	5850	300		40	90	40
19	5550	300		41	55	30
20	5250	300		42	30	20
21	4950	300		43	10	20
22	4650	300				

4.1.2 DRI Weather Stations

Efforts were coordinated with the Desert Research Institute (DRI) to research, acquire, install, and operate four surface weather sensors at designated locations throughout the Fallon range complex (Wetzel 2006). In coordination with NPMOD Fallon and the range operators, the selected locations were the three active bombing target ranges, Bravo 17 (B17; also the location of the Centroid facility), Bravo 19 (B19), and Bravo 20 (B20), and a prominent North/South valley, EW-71 (Table 4 and Figure 2). Each meteorological system has sensors and data logging for wind speed and direction, humidity, precipitation, station pressure and precipitation measurements as well as soil temperature. It was determined that only the B17 site has sufficient power availability to operate the ceilometer and visibility sensor, so only this location has those additional instruments. The B17 site has a 10-meter tower and the sites at B19, B20 and EW-71 utilize a tripod support for the data logger shelter and instrumentation. Sensors are mounted at or close to a 2-meter height except for the 10-meter wind sensor height on the B17 tower.

Data communication is accomplished via the NOAA NESDIS GOES Data Collection Platform (DCP) satellite transmission uplink system that is utilized for many of the DRI Western Regional Climate Center (WRCC) network monitoring stations, and the data are accessed from NESDIS using automated retrieval from the WRCC computer system. Transmission is made at approximately 20 minutes past each hour, and includes data parameters at 10-minute observation frequency. The satellite communications and processing sequence through NESDIS to DRI normally allow data collection and web access within 10 minutes of that hourly transmission so that hourly updates of the 10-minute observations for the previous 60 minutes are accessible at approximately 30 minutes past each hour. Nowcast incorporates the data by downloading it from the MesoWest website.

The sites were installed beginning in October 2005. The installation of all sensors was completed in mid-December 2005. An external contract (Stan's Electric, Fallon NV) was required for the electrical cabling from a Centroid facility power drop to the tower site for ceilometer and visibility sensor. Listed in Table 5 are the sensors and associated equipment for data collection, communications, power and maintenance that are installed at the sites.

Acquiring and incorporating near real-time in-situ data is an incredibly important feature in the development of Nowcast and has greatly increased the value and usability of Nowcast products at Fallon. As shown in Figure 2, adding four surface observation stations to an extremely data sparse area influenced by complex terrain has significantly aided forecasters and war-fighters in planning, altering, and cancelling exercises.

Table 4. Detailed information about the location of the DRI surface stations.

Name	Location	Position	Elevation	Directions
B17	Fallon 31ESE at the Centroid in Fairview Valley	39°19'27" N, 118°13'22" W	4235 ft MSL	Location from NAS Fallon: 23 miles range at 99 degrees azimuth
B19	Fallon 23SSE at Blowing Sand	39°08'31"N, 118°40'01"W	3886 ft MSL	Location from NAS Fallon: 16 miles range

	Mountains			at 164 degrees azimuth
B20	Fallon 36NE at Carson Sink	38°54'40" N, 118°23'14" W	3881 ft MSL	Location from NAS Fallon: 31 miles range at 13 degrees azimuth
EW-71	Fallon NAS EW Complex at Edwards Creek Valley	39°31'57" N, 117°44'50" W	5192 ft MSL	Location from EW Complex: 11 miles NE from Cold Springs, NV

Table 5. Surface sensor station detail for the DRI sites.

System components at the four meteorological sites
Vaisala HMP45C-L Air Temperature and Relative Humidity Sensors
41003 RM Young Gill Solar Radiation Shield
Setra 278 Barometer
RM Young 05103-L Wind Speed and Direction Sensor
Texas Electronics TE525 Precipitation Gauge
LICOR Solar Pyranometer with Mounting and Leveling Base
Campbell Scientific CR1000 Data logger
Campbell Scientific CR1000WP Insulated Terminal Cover
Campbell Scientific CR1000KD Keyboard/Display Unit
Campbell Scientific Weather Resistant Data logger Enclosure
Campbell Scientific MSX20 20-Watt Solar Panel
Campbell Scientific CH100 12-V charger and regulator
Campbell Scientific DCP Satellite Transmitter
Campbell Scientific YAGI Satellite Antenna and cabling
Sensor, power, and communications cabling
12-Volt Auxiliary Power Storage Battery
Surge Suppressor Kit
Campbell Scientific Sensor Mounting Arms
Campbell Scientific TX312 GPS Antenna Cable
For sites B19, B20 and EW-71: Tripod support for meteorological data logger shelter and sensors
Additional equipment at the Centroid site (B17)
Vaisala PWD20 Visibility Sensor
Vaisala PWH111 Hood heater unit for Visibility Sensor
Vaisala PWA11 Calibration Set for Visibility Sensor
Vaisala RS-232 Cabling for Visibility Sensor
AllWeather 8339-D Laser Ceilometer
AllWeather 83391 Heater Blower Unit for Ceilometer
AllWeather data and power cabling for Ceilometer
UT30 Universal Aluminum 10-meter Tower
UT Tower Guy Kit
B18 Tower Base
UT30 Tower Grounding Kit

4.1.3 Unmanned Aerial Vehicle Observations

UAV data have been integrated into the Nowcast system. Atmospheric observation data from the Predator UAV are contained in the data stream returned from the aircraft to the ground control station for aircraft control purposes. The data are sent out a serial port on the front of the ground control station. In coordination with Air Force operations at Creech Air Force Base, NV, a computer attached to the port captures the weather observation data, averages it, produces observations every 1000 feet on ascent or descent or every five minutes in level flight, and writes the data in AMDAR format to a file. Every fifteen minutes the file is transmitted to a web site hosted at NRL Monterey where it was inserted into the normal observation data stream and ingested into the TEDS database. The UAV data includes time, location, pressure altitude, wind speed and direction, and air temperature.

4.1.4 KNFL High Frequency METAR Surface Observations

The METOC Integrated Data Display System (MIDDS) at NPMOD Fallon normally distributes the local METAR reports hourly. Without any intervention, the KNFL (KNFL is the NAS Fallon call sign) METAR reports are included in the regular hourly AWN data, making their way into the TEDS database.

During a site visit to Fallon, Nowcast developers worked with NPMOD Fallon to make the data available every minute. A commercial software application called 'WatchDirectory' was purchased and installed on Fallon's MIDDS computer. WatchDirectory is able to push the KNFL METAR reports to NRL at the higher temporal frequency. These reports were then ingested into the TEDS database.

Fig. 2. Regional view of Fallon Naval Air Station with locations of four meteorological tower sites (B17, B19, B20, and EW-71), in relation to highways 50, 80 and 95, and local topographic features.

4.1.5 Fallon Supplemental Weather Radar (SWR)

Weather radar data is one of the major new components of the NRL Nowcast system and played an important role during the Nowcast Fallon demonstration. Real-time data from the SWR and 13 WSR-88D radars in the surrounding area, were processed, quality controlled, and fused with other sensor data to provide near real-time 2D and 3D products every 5-10 minutes for observing and nowcasting high-impact weather for NSAWC operations.

By working very closely with the NPMOD Fallon, tremendous efforts were made in re-configuring the SWR and transferring the real-time radar data to NRL Monterey for processing. During a site visit to Fallon, the Nowcast developers gained familiarity with the Enterprise Doppler Graphics Environment (EDGE) SWR control and analysis software in order to optimize the internal data quality control settings and maximize scan parameter settings while minimizing volume scan duration to fit the Nowcast radar data frequency requirements. Specifically, the EDGE quality control parameters were adjusted to maximize the amount of reliable spectrum width data while simultaneously minimizing the competing increase in noise within the radial velocity data. In addition,

the operational SWR volume scan was re-configured: the range resolution of all radar data was increased from 1000 to 250 meters; the data coverage at low altitudes was increased by appropriately choosing one extra low-elevation angle surveillance scan; the Nyquist velocity (maximum detectable radial velocity before unfolding) was increased by a factor of three by using the 4:3 dual pulse repetition frequency option that EDGE affords. All of these improvements were accomplished while approximately maintaining the previous 150 km maximum range of data collection and volume scan duration of less than 7 minutes (in keeping with similar WSR-88D scan durations). After each volume scan completes, the system produces a compressed universal format (UF) file of radar data. Because the SWR system only has network access to MIDDS, it was necessary to set up transmission of the UF files to the MIDDS system where the commercial WatchDirectory application is again used to transmit the data to NRL where it is introduced into the normal radar data feed.

4.1.6 ADAS Cloud Analysis System

A three-dimensional cloud analysis system originally developed at the NOAA's Global System Division (formerly the Forecast Systems Laboratory - FSL) as a part of the Local Analysis and Prediction System (LAPS), and later modified by the University of Oklahoma (OU) as a part of the ARPS Data Assimilation System (ADAS), was adapted and integrated into COAMPS-OS for 3D cloud analysis and nowcasting. The system retrieves cloud information from geostationary satellites, radars and surface observations with COAMPS forecasts as background fields and then analyzes and fuses the retrieved cloud data to produce three-dimensional mixing ratios of cloud liquid water, cloud ice, rain water, snow and graupel. At NRL, ADAS was modified with a new capability to automatically extract COAMPS grid information from the model data header and then to perform the cloud analyses directly on the COAMPS nested grids. In addition, a cloud verification system was also developed and added to ADAS to verify the 3D cloud analyses from ADAS and the cloud forecasts from COAMPS against satellite observations. Both the cloud analysis and verification systems are running hourly over the Fallon area and provides 3D cloud analysis fields that are used to generate products for Nowcast such as cloud fraction, ceiling, and visibility.

4.1.7 Thunderstorm Tracking and Nowcasting Using NCAR TITAN

The NRL 3D reflectivity mosaic system was recently developed at NRL Monterey. The system processes reflectivity data from one or more radars in an area of interest, and then optimally interpolates these data from the radar native semi-spherical coordinates to a common 3D grid for easy applications to storm study, NWP verification and data assimilation. The system is globally re-locatable and automated to use any 3D grids, domain size and grid resolution, and therefore suitable for military uses and field experiments. Using data from the SWR and 13 nearby WSR-88D radars, the system is currently used to generate 3D reflectivity mosaic data sets every 10 minutes for the Fallon area.

The Thunderstorm Identification, Tracking, Analysis and Nowcasting (TITAN) system (Dixon and Weiner 1993) was developed by the National Center for Atmospheric Research (NCAR) and has successfully demonstrated its usefulness in storm identification, tracking, and nowcasting in the literature. It extrapolates and trends existing areas of precipitation using sophisticated software that includes combinatorial optimization and allowances for storm cell splits and mergers. With the assistance of NCAR, TITAN has been implemented into Nowcast using real-time reflectivity data from the SWR and the 13-chosen WSR-88D radars in the surrounding area. The data are processed and quality controlled at NRL and then ingested into the NRL 3D reflectivity mosaic system to provide the input data for TITAN; 30-minutes, 1-h and 2-h TITAN storm predictions are created every 10 minutes. Figure 3 gives an example of 2-hour prediction of storms for Fallon area on February 28, 2006. TITAN has also been applied to archived data from the Navy's phased-array radar at the National Weather Radar Testbed in Norman, OK, as well as both land- and sea-based SPS-48E archived radar data provided by SPAWAR. Evaluation of the TITAN system performance has also been conducted by NRL and NCAR for all these data sets and presented at several conferences. The MIT Lincoln Lab (MIT LL) Storm Tracker software, which is similar to TITAN except that it tracks precipitation from reflectivity correlations between consecutive radar scans, was recently delivered to NRL and is currently being evaluated and compared to TITAN.

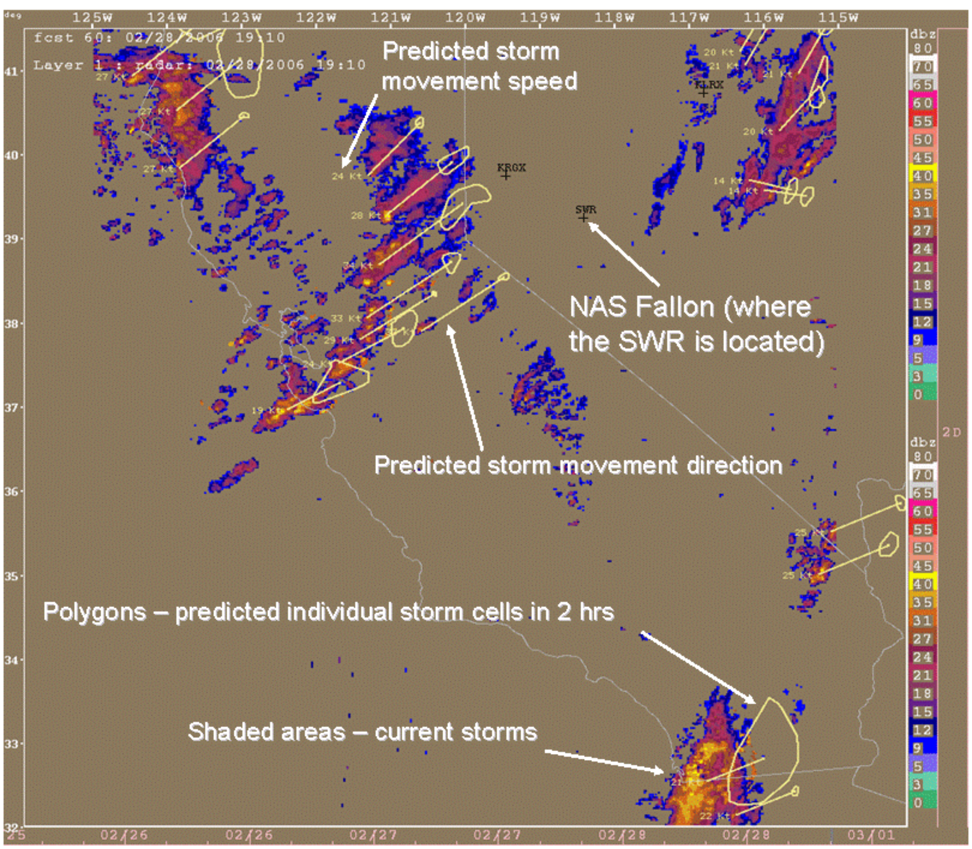

Fig. 3. Example of NCAR TITAN storm tracking and prediction using radar data from the NRL 3D composite, including radar data from the Fallon SWR. Current storm

locations and intensities are given by the colored areas while the predicted storm locations (with reflectivity > 20 dBZ) in 2 hours are indicated by polygons.

4.1.8 Lightning Observations

Prior to the RTP, a commercial lightning data feed was purchased from Vaisala. The data feed provides the lightning data in a real-time continuous stream. The data are decoded and superimposed on the Nowcast displays of composite reflectivity to help identify regions of thunderstorms. This data may also used by TITAN as a proxy for reflectivity in regions of no radar echo. Figures 8 and 17 show two examples of lightning data displayed on Nowcast during periods of widespread thunderstorms in the Fallon area.

4.1.9 Fleet Numerical Meteorology and Oceanography Center

Though not a partnership specific to the RTP, FNMOC plays an important role in providing data for COAMPS-OS and various components of Nowcast. FNMOC provides a feed of observation data and global lateral boundary conditions that are used to initialize the COAMPS model. This data feed includes the standard suite of NOGAPS data, conventional observations from the AWN feeds, and remotely sensed satellite data.

4.2 DATA PROCESSING AND QUALITY CONTROL

4.2.1 Meteorological Quality Control

The quality of COAMPS-OS surface forecasts of temperature and winds are scored by Meteorological Quality Control software (MetQC) using hourly observation reports at NAS Fallon and by the DRI field weather sensor stations at Bravo 17, 19, and 20. Software was developed that downloads the sensor data from the DRI website and ingests it into the NRL TEDS. Once in TEDS, the sensor data are treated the same as other surface data and they are available for both display and modeling. The confidence gained by the verification scores observed at these sites assured the forecasters and planners that surface wind forecasts in the Fallon range are reliable and should be heeded to avoid hazardous conditions. Similar confidence gained in the forecast of cloud layers significantly aids the daily planning of training missions. Figures 4a and 4b are examples of COAMPS-OS web page graphic showing the high level MetQC display for the KNFL site. Each time series represents about three days of hourly data. The example shows a consistent issue with the COAMPS surface air temperature forecasts – the model routinely forecasts the overnight low temperatures to be too high; the daytime high temperatures agree much better than the nighttime low temperatures with the observations. The lack of a strong diurnal cycle forecast for the high desert region indicates a potentially unresolved problem with the surface model used in COAMPS. A more sophisticated model of the surface and subsurface layers may improve the nighttime low temperature forecasts.

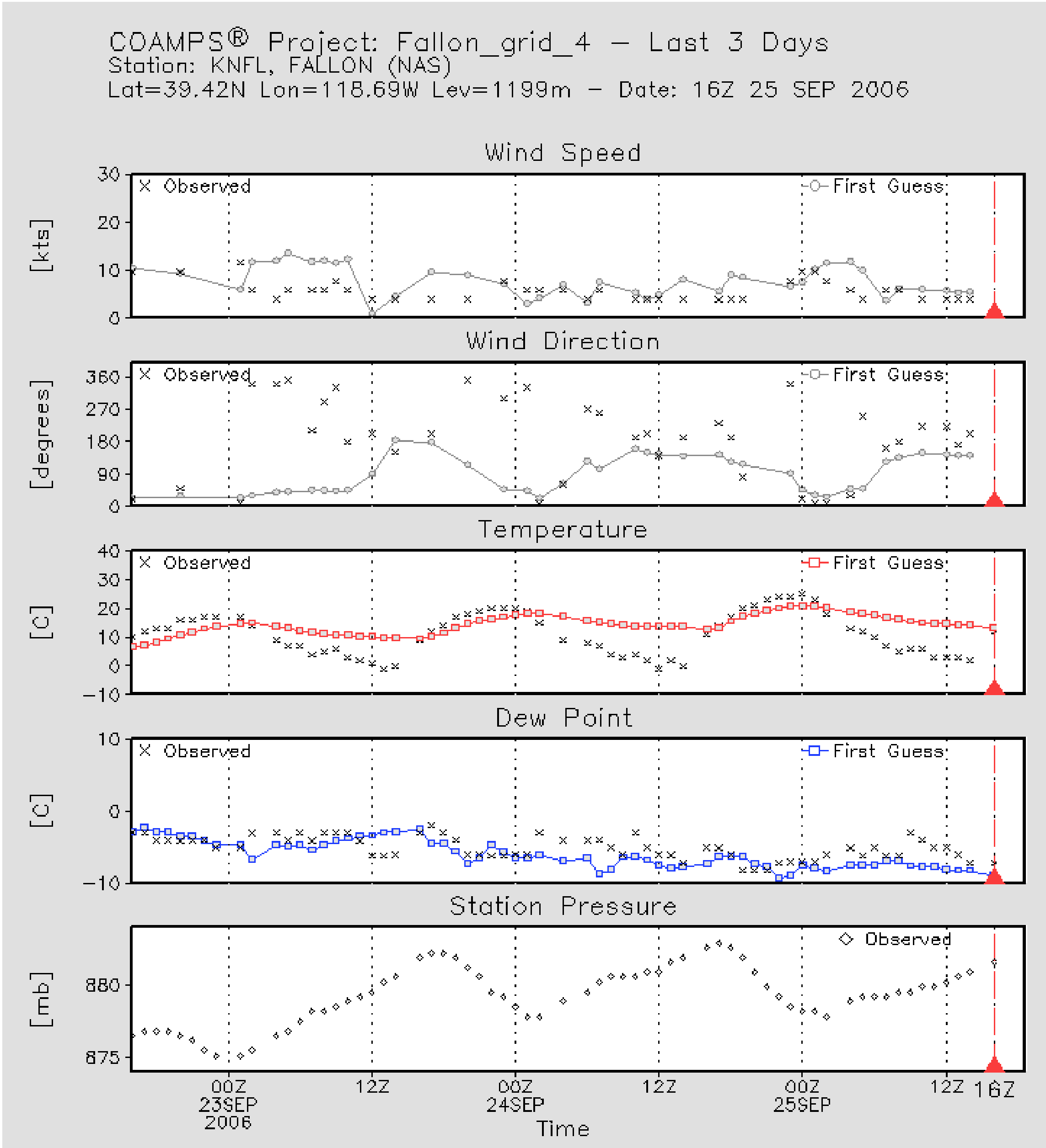

Fig. 4a. MetQC web page graphic for station KNFL (NAS Fallon) showing time series of observations and model forecasts. Station pressure forecasts were not processed.

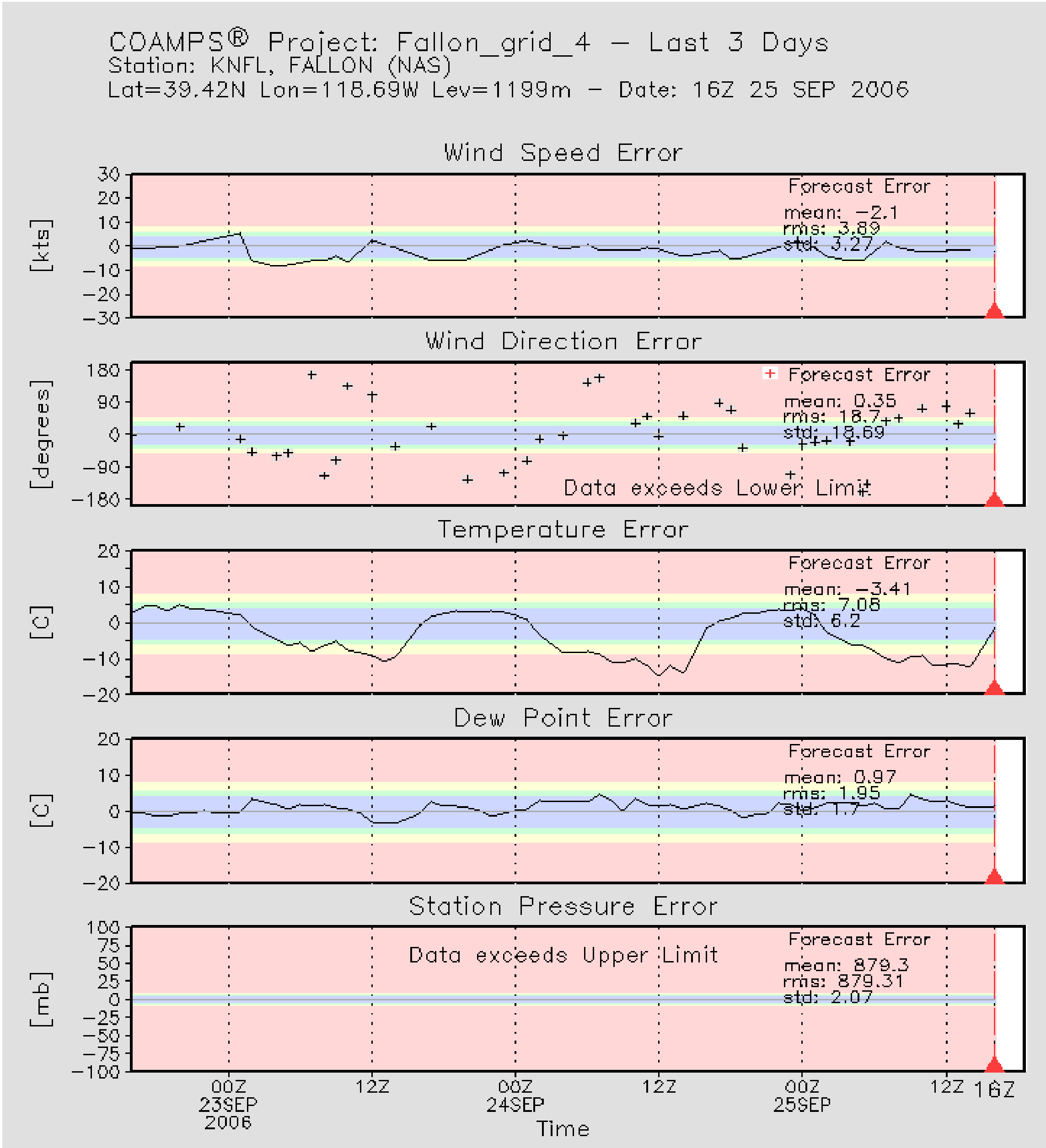

Fig. 4b. Corresponding MetQC web page graphic for station KNFL (NAS Fallon) showing time series of forecast errors verified against observations. Station pressure forecasts were not processed.

4.2.2 Radar Data Quality Control

By collaborating with scientists at NCAR, University of Oklahoma, NSSL, and MIT LL, a new system suitable for DoD radar data processing and quality control has been developed, tested and applied to both the SWR and WSR-88D data used in the Fallon domain. This included the development of software to remove anomalous propagation clutter and constant power function artifacts (Figure 5). NRL also developed and implemented its own novel, radial velocity dialing and enhanced Velocity Azimuth

Display (VAD; Figure 6) algorithms that combine both Gradient VAD (GVAD) winds and COAMPS skew-T winds for initialization and quality control. In addition, a site-specific normal propagation ground clutter filter (Figure 7) was developed and implemented for real-time use with the SWR data displayed in Nowcast since no such system was available locally with the EDGE radar data processing and display at KNFL. This filter removes the extensive radar echoes from the mountain ranges around Fallon, and also serves to identify any problem with the SWR alignment, which is sometimes re-set during SWR maintenance (see Section 6 'Lessons Learned' for a case in point).

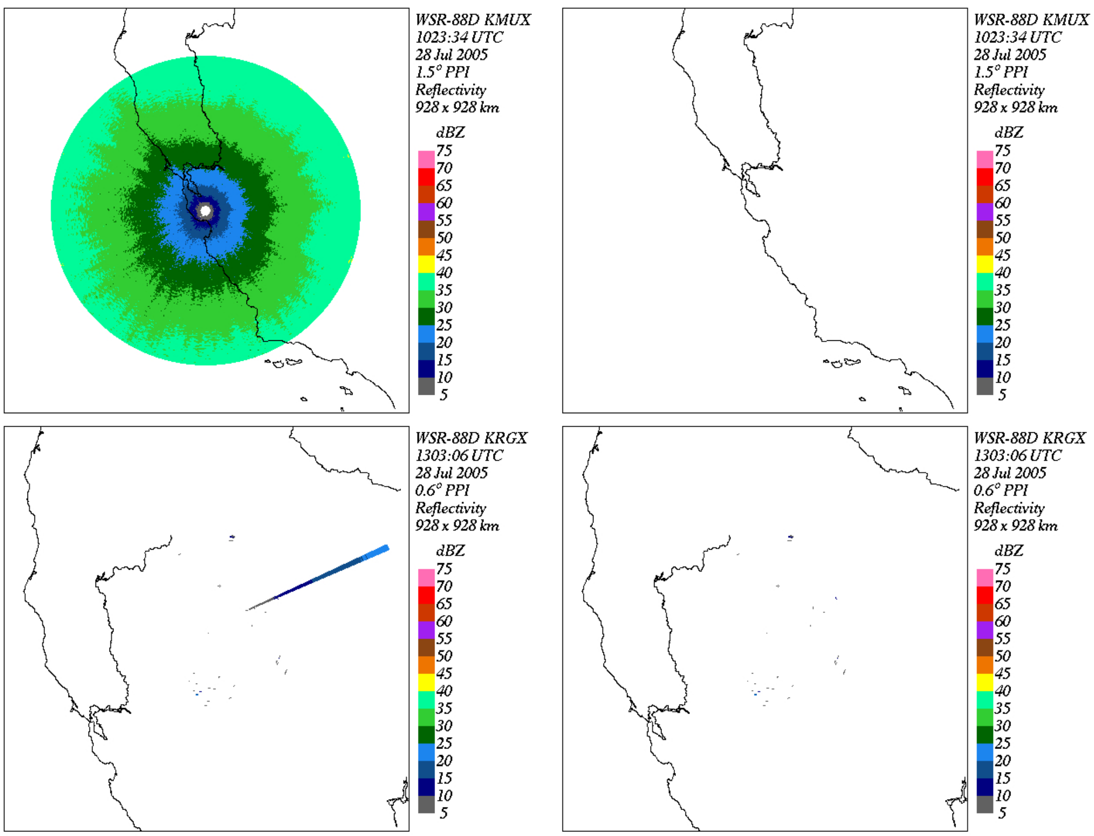

Fig. 5. Examples of MIT LL quality control (QC) of constant power function artifacts, such as a bulls eye pattern (top) and sun strobe (bottom); left panels are before QC and right panels are after QC. This MIT LL artifact detector is now operational in real-time in Nowcast supporting the QC of these and other WSR-88D radar data used to create the 3D radar mosaic for the Fallon domain which includes the Fallon SWR.

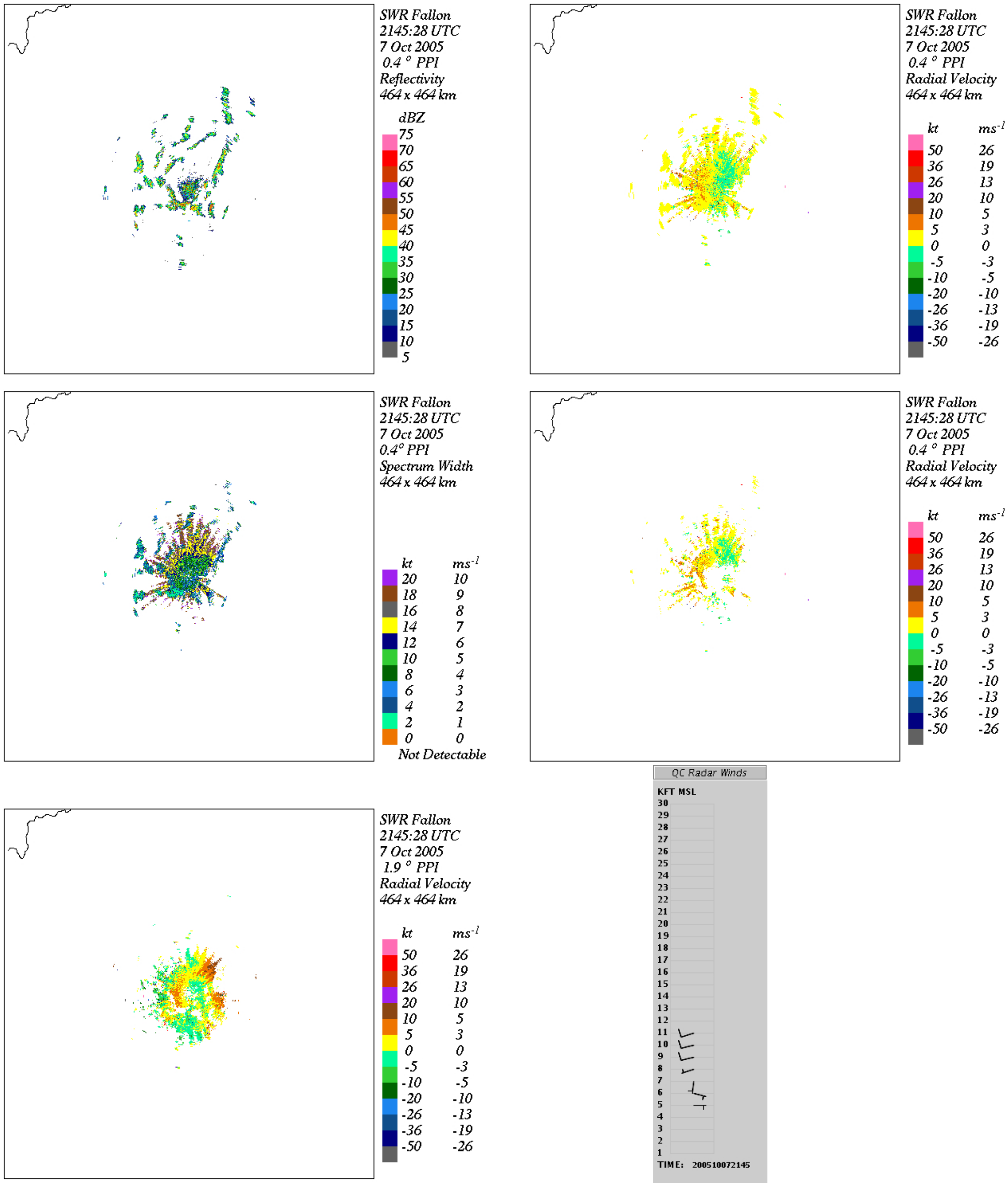

Fig. 6. Examples of clutter filter success during a weak echo event. Top panel shows the lowest-tilt reflectivity and radial velocity before QC, where the reflectivity only shows the ground echo returns from the nearby mountain ranges. Note the clear-air (insects) echoes are only shown in the velocity because their reflectivity echoes are less than the 5 dBZ display threshold. Middle panel shows the lowest tilt spectrum width with ground clutter present (discussed in Section 6 'Lessons Learned'), along with the lowest-tilt, quality controlled velocity. Bottom panel shows the fourth-tilt quality controlled velocity, with the S-shaped zero isodop line indicative of veering winds with height, along with the quality controlled VAD wind profile verifying these veering winds (radar is at approximately 4000 ft MSL). Owing to the deceiving lack of weather echo in the

reflectivity, this valuable wind profile would have likely been unnoticed and unavailable without the Nowcast ground clutter removal filter.

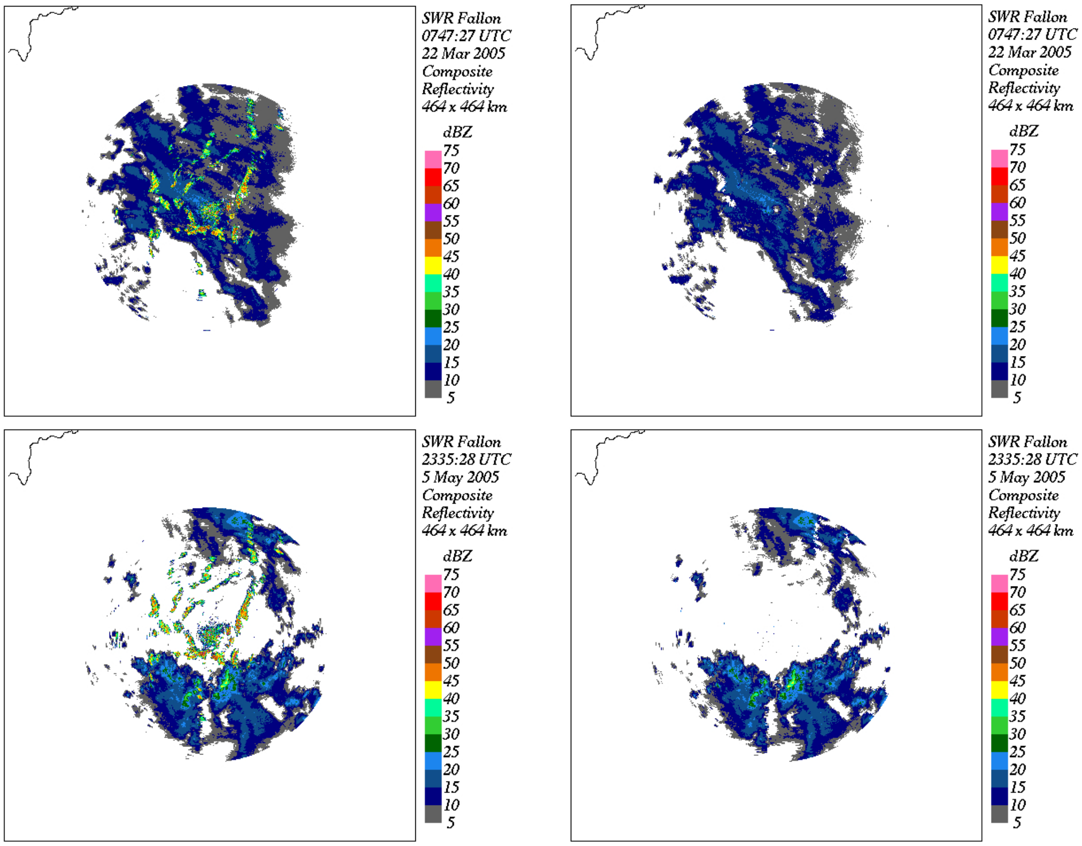

Fig. 7. Examples of the QC of ground clutter by the SWR ground clutter filter implemented in Nowcast. The composite reflectivity of two different precipitation events are shown from top to bottom with the raw data shown along the left panel and the quality controlled data shown along the right panel. Note that the majority of the extensive mountain range echoes are removed in both cases leaving only the precipitation after QC.

4.3 PRODUCTS

The Nowcast products were designed for both METOC officers and warfighters. The basic requirements are that i) the products should be sophisticated enough to contain all the major parameters that indicate the current and near future atmospheric conditions and ii) they should be easy to understand by warfighters who do not have formal meteorological training. The original motivation for the Nowcast display was data fusion and integration. As shown in Figure 8, in one application interface the user can see all available data types overlaid graphically and updated automatically. This web-based design was conceived to alleviate the burden of having to look at five different data systems to see five different data type displays on five different maps. Nowcast focused primarily on supporting the Naval Pacific METOC Detachment (NPMOD) Fallon with short-range, mesoscale forecasts of standard weather parameters such as winds and

temperature augmented with satellite and radar overlays, and provided these on a display in the NPMOD forecaster station. This information and format was designed specifically for the forecasters and the design proved useful to them when asked about it. However, there proved to be two hurdles in getting Nowcast products available for operational aviation users at the Naval Strike and Air Warfare Center (NSAWC). First, with the delay of installing an unclass-to-class network data pump, potential users of Nowcast at NSAWC would never get a chance to interact with Nowcast firsthand over the SIPRNET. Second, despite the training on Nowcast and visits to NPMOD, forecasters were not routinely using the capability. To comply with DoD unclassified network mandates, user authentication using Public Key Infrastructure (PKI) technology was required to load the software. Furthermore, because the Nowcast application requires current versions of Java, only the single Navy Marine Corps Internet (NMCI) S&T seat at NPMOD Fallon has the appropriate software configuration to run Nowcast. Taking into account these impediments, a new approach needed to be developed.

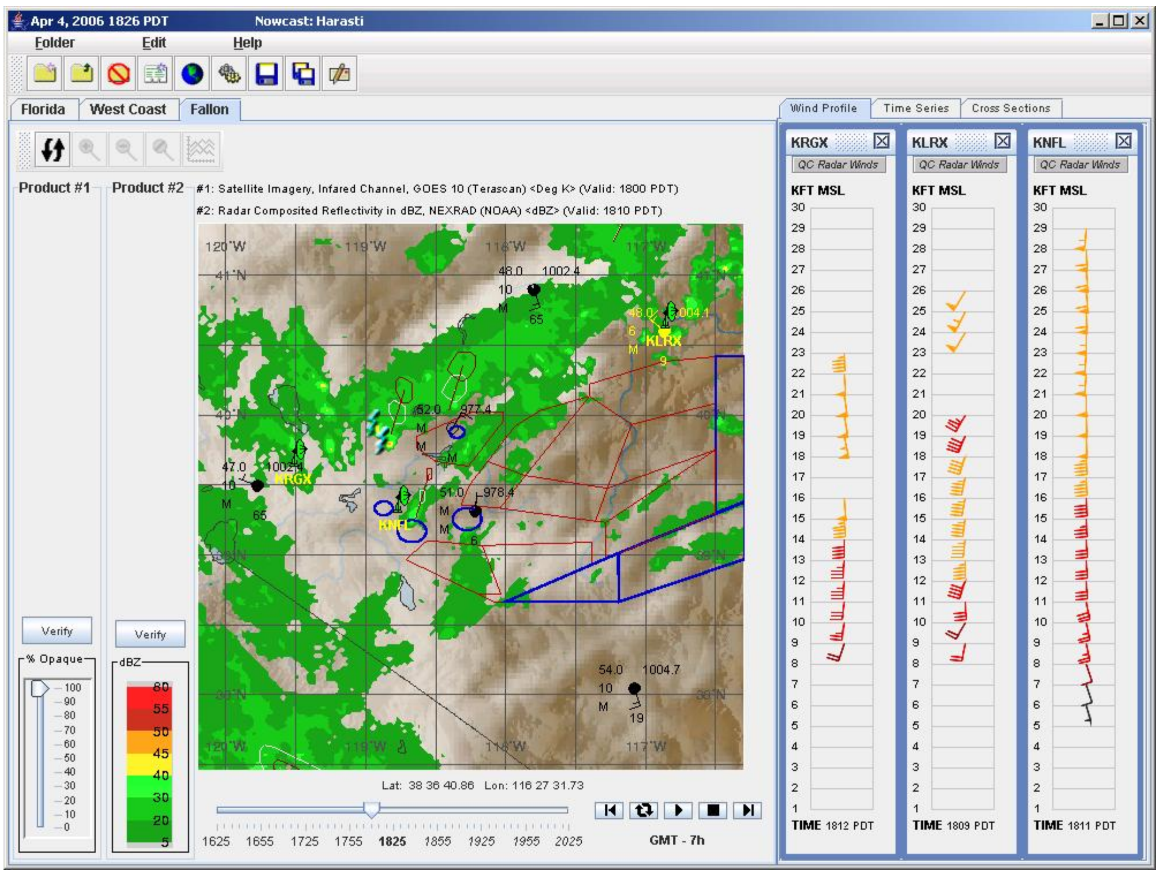

Fig. 8. Example of the fusion of Nowcast products over the Fallon domain within the original Java web-based display. The infrared satellite imagery of the clouds is shown as a white translucent layer over the background. The composite reflectivity of storms are shown in green, which includes the quality controlled SWR data from Fallon (KNFL) along with 13 nearby WSR-88D units. The upper rain band shows 30- and 60-minute TITAN storm cell forecasts by the white and black polygons, respectively, with a black line showing direction of movement and leading back to the cell being forecast. The blue

lightning bolts show the location of embedded cloud-to-cloud lightning strikes. The right panel shows VAD wind profiles from the Fallon SWR (KNFL), and Elko (KLRX), and Reno (KRGX) WSR-88D radars. The KRGX and KLRX VAD winds are provided by a feed from the WSR-88D NIDS Level III data network whereas the KNFL VAD winds were calculated from the SWR radial velocity full-resolution (i.e., Level II) data for Nowcast using the enhanced-QC NRL VAD wind algorithm.

Interviews were conducted with the strike and helicopter aviators to understand their specific forecast requirements in order to provide products in a format better aligned with their pilot training exercises. The interviews with strike pilots revealed the need for forecasts that included flight level winds and surface visibility and cloud structures along their routine flight corridors, out to the rendezvous point, and back to the target area. Surface visibility and clouds impact target detection and clouds impact flight levels. Similar interviews with helicopter pilots revealed the need for forecasts of surface winds and visibility in target and rescue areas since safe operations cannot be conducted if winds exceed 25 knots and horizontal visibilities are less than a few thousand feet.

These interviews were repeated over a series of visits to design and refine automated products that provide a combination of cloud, visibility, surface wind, satellite and radar maps and a set of cloud and wind vertical cross-sections along two corridors and at four keys sites using an new web-based application interface design that did not require user authentication over the network.

Nowcast developers learned the general steps of air warfare training operations at NSAWC and worked with aviators and strike operations directors to develop a suite of products displayed in a fashion that would prove instrumental in planning and coordinating training missions. A large format 55” flat screen monitor and accompanying computer were purchased for display directly in the Strike Operations Center (SOC), solely dedicated to the web broadcast of animating weather forecast products tailored to the warfighters’ specific needs. The animating product suite is hosted on a web server at NRL Monterey located in the network DMZ. The fixed product suite includes the following products for 0, 1, and 2 hours future, for a small domain covering the extent of, and highlighting specific locations within, the Fallon Range Training Complex: surface visibility (displayed in text in statute miles), surface winds (colored vectors in knots that vary as specific safety thresholds are breached), cloud layers (displayed in text as cloud type in hundreds of feet, similar to a TAF), and vertical cloud cross-sections, across the four main bombing ranges and across Fallon itself, that depict physical representations of the presence of clouds. The cloud cross-section products also display a wind profile, helpful for determining which target ranges to use for certain strike missions. Furthermore, two additional history-to-real-time products round out the suite: infrared satellite and composite radar reflectivity (Fallon SWR and 13-chosen WSR-88Ds). Both of these products also overlay the station observations from conventional surface stations in the area and the four DRI stations installed in the range complex for this project. Additionally, polygons and circles denoting the range operations areas were added to facilitate locating forecast weather conditions on the range.

All of the <u>forecast</u> products are derived using COAMPS model data from the COAMPS-OS project positioned over the Fallon area. As previously described, the project has four meshes, the innermost set to 2 km horizontal grid spacing with 43 vertical levels, highly concentrated near the surface for increased low level vertical resolution. This high resolution innermost mesh is what is used to derive the products on display in the SOC. Examples of the automatic SOC display products are shown in Figures 9a-g.

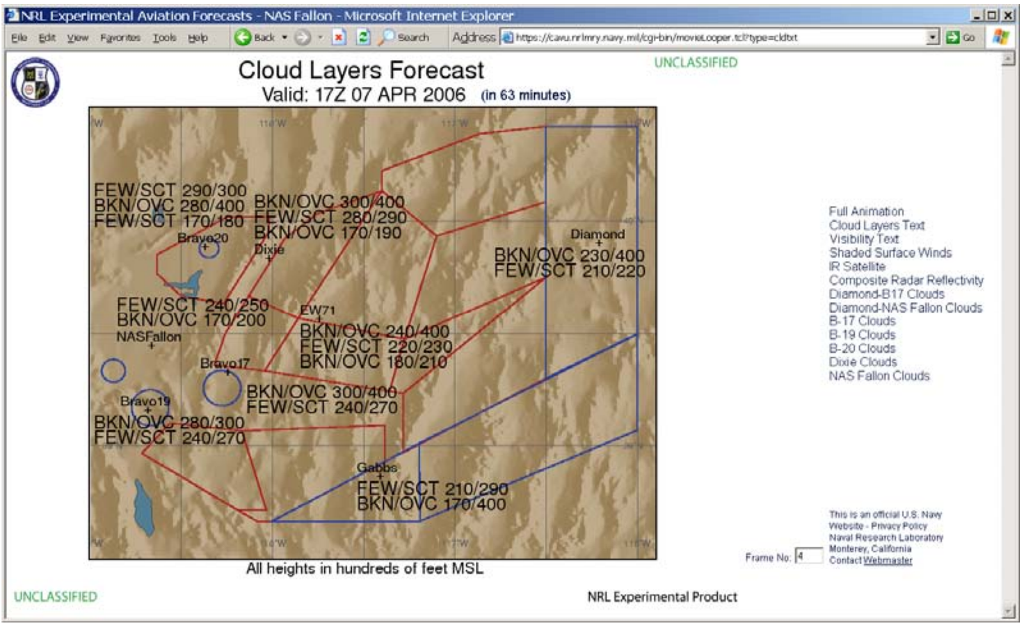

Fig. 9a. Automatically refreshing web page showing the alphanumeric Cloud Layers Forecast product displayed in the NSAWC Strike Operations Center (SOC), continuously animated and updated hourly on the dedicated large screen display.

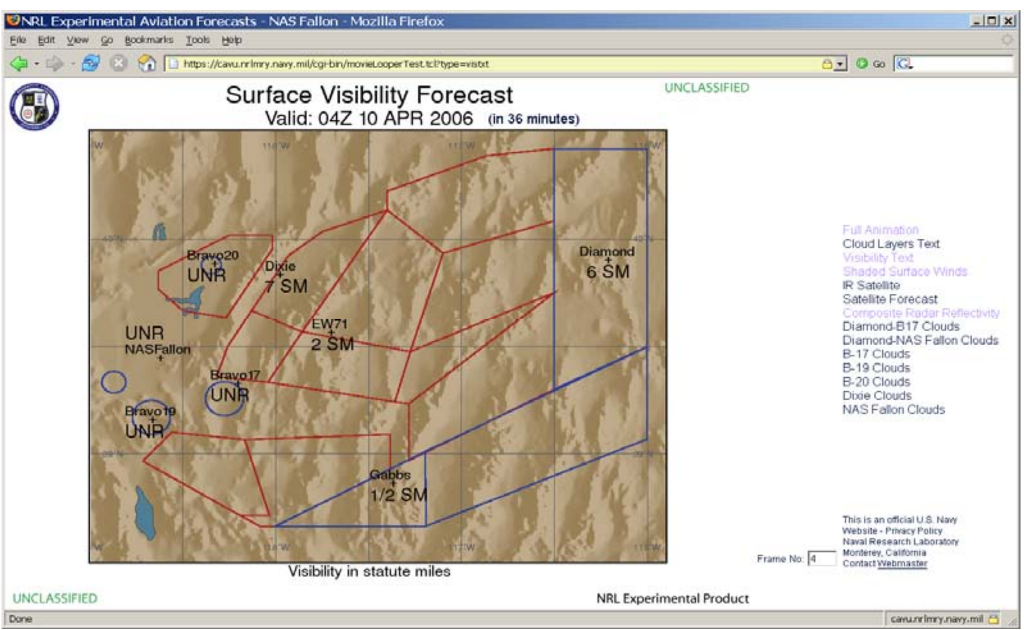

Fig. 9b. Similar to Fig. 9a except for Surface Visibility Forecast SOC product.

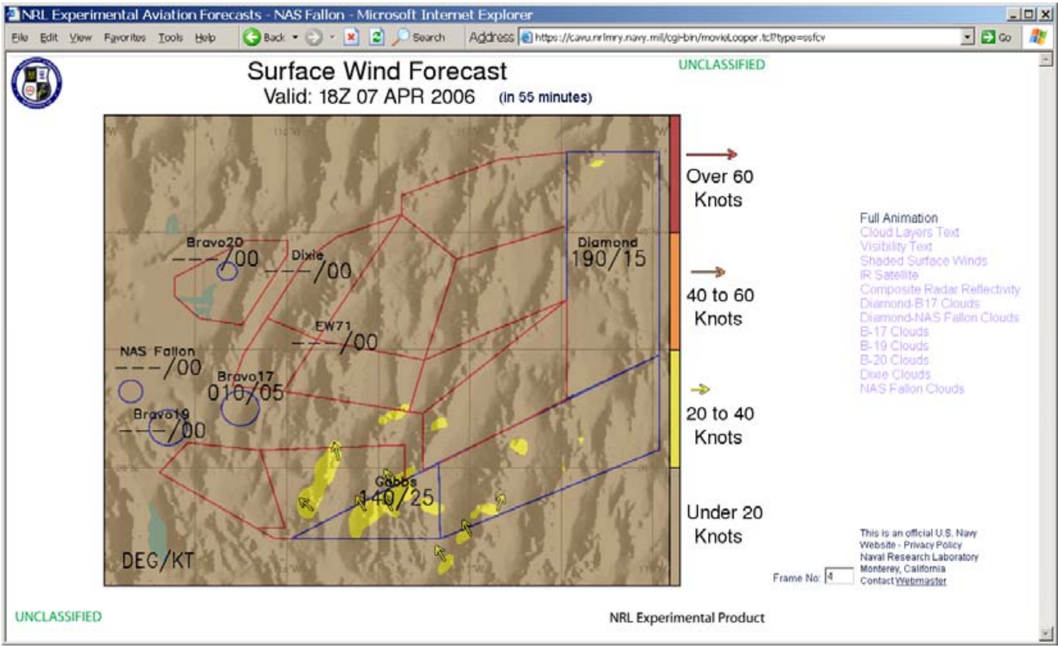

Fig. 9c. Similar to Fig. 9a except for Surface Wind Forecast SOC product. This product also highlights areas where the wind speed is expected to exceed operator thresholds. Surface wind vector graphics are also displayed for those areas.

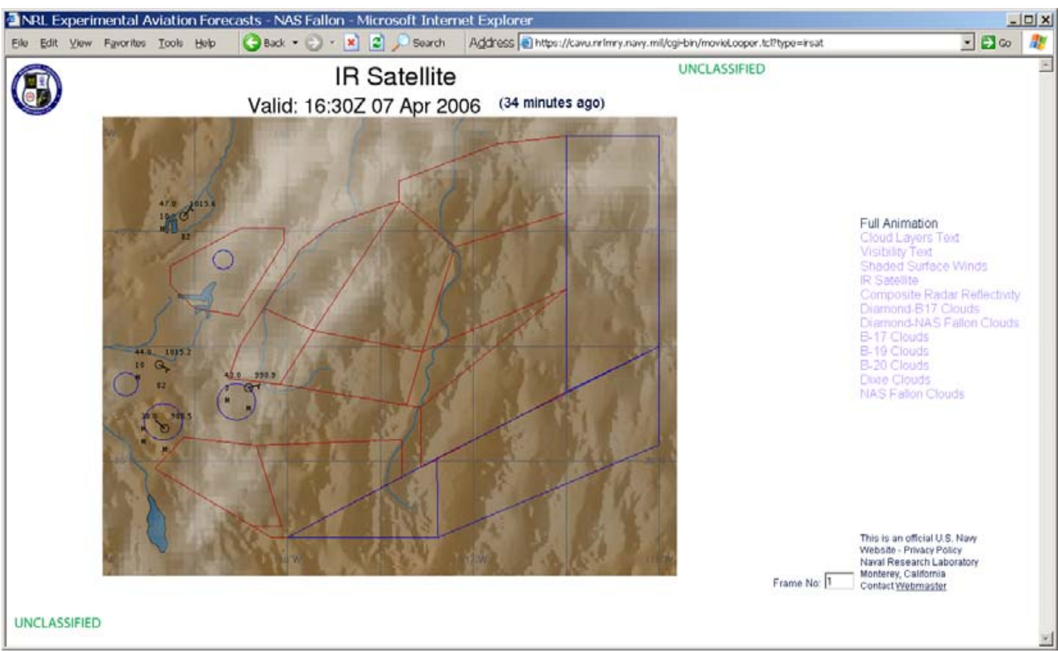

Fig. 9d. Similar to Fig. 9a except for IR Satellite SOC product. This product and the radar reflectivity product display a short-term history when animated, without a forecast as for all the other SOC products.

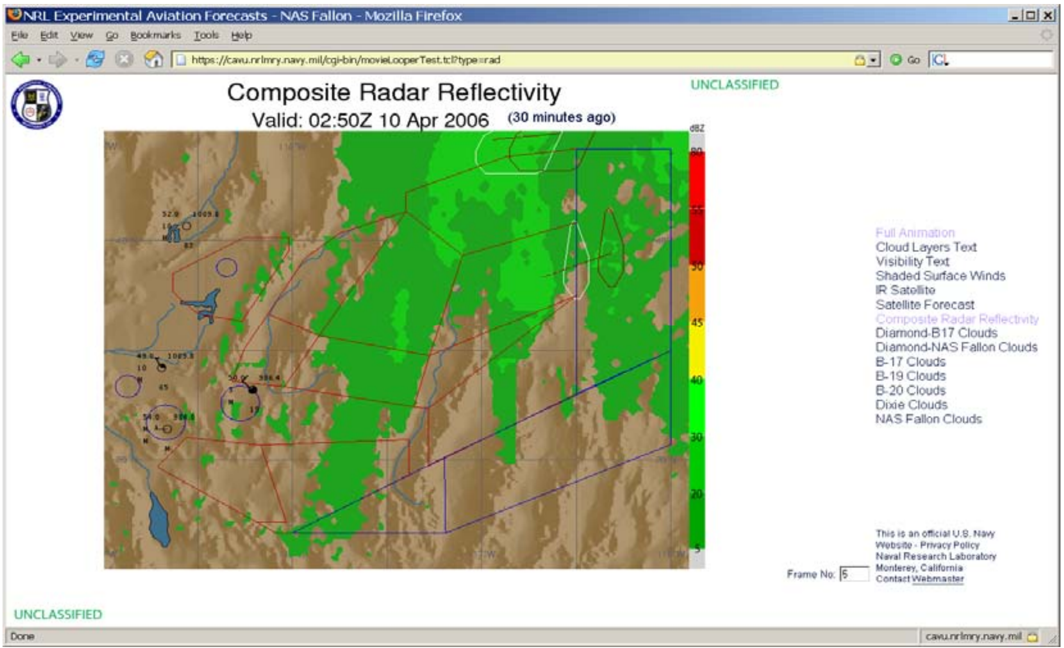

Fig. 9e. Similar to Fig. 9d except for Composite Radar Reflectivity SOC product. This product also shows the TITAN 30 and 60 min thunderstorm cell forecast polygons and thunderstorm movement direction.

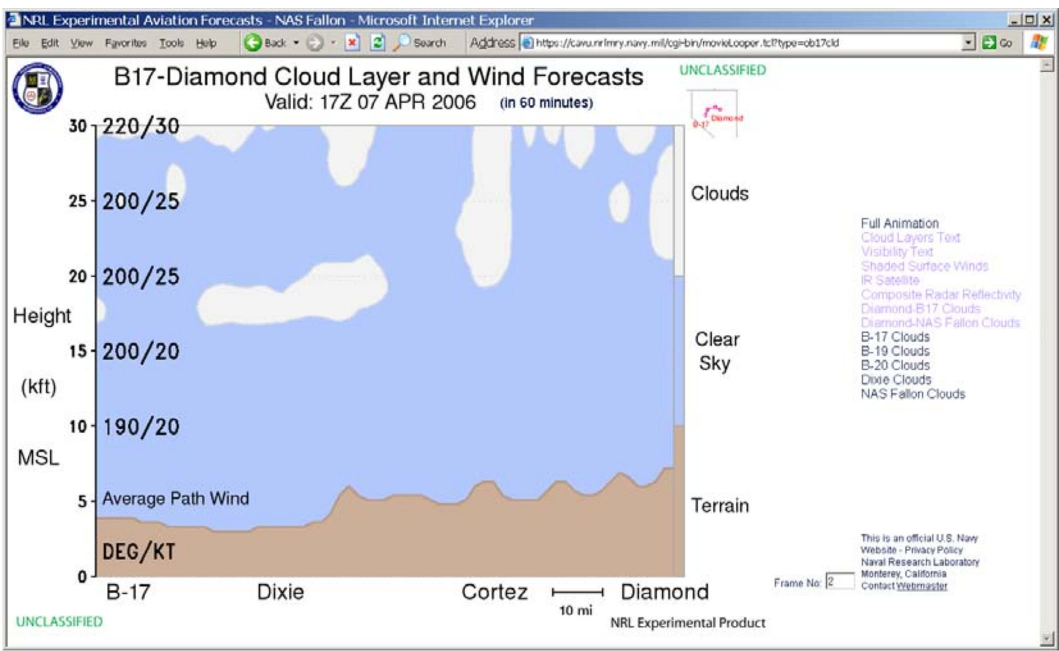

Fig. 9f. Vertical cross-section of B17-Diamond Cloud Layer and Wind Forecasts SOC product. B17 refers to Bravo 17, a heavily used bombing range and Diamond refers to an area frequently used to rendezvous during a training mission. The distance legend is shown at the bottom of the graphic. Cloud and wind information are derived from COAMPS with the wind profile averaged over the path. A similar product (not shown) also displayed a southerly cross section along the route from Diamond to NAS Fallon.

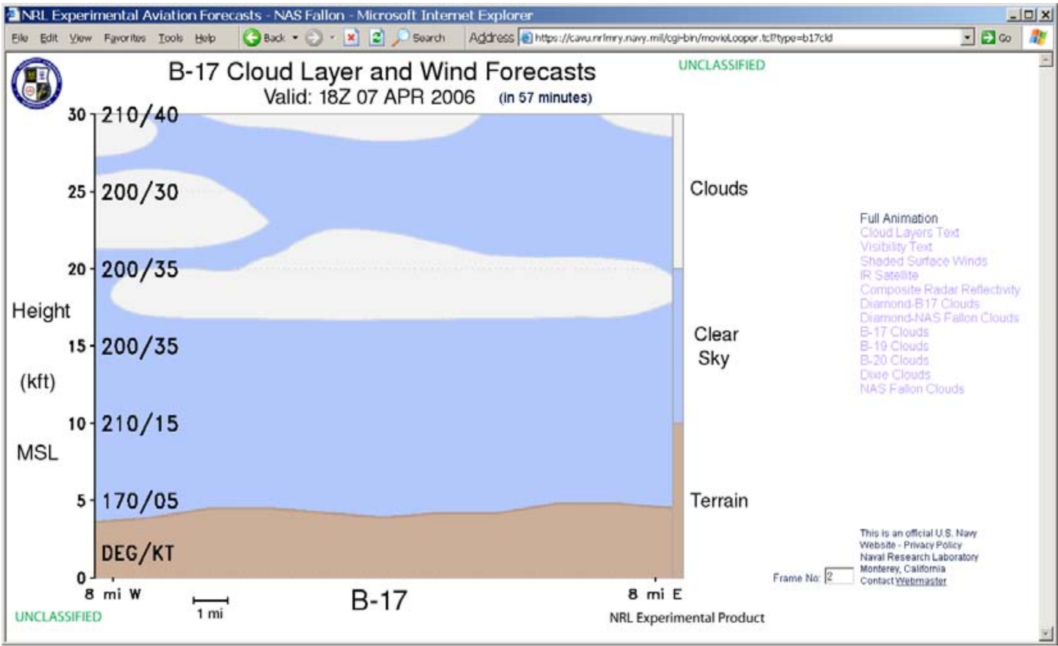

Fig. 9g. Similar to Fig. 9f except for B-17 Cloud Layer and Wind Forecasts SOC product. In this case, the horizontal scale (16 mi) is much smaller than the route shown in Fig. 8e. Similar products (not shown) are also displayed for the B-19 and B-20 bombing ranges, the Dixie electronic warfare range, and Fallon NAS.

In Figure 9, the cloud layers text forecast product relies on the high vertical resolution of the innermost COAMPS mesh. There are eight designated locations across the range training complex that are of particular interest for various exercises. The eight locations are each centered inside a 9x9 sub-grid. The sub-grids are stacked throughout the volume at each vertical layer, resulting in a 9x9 column extending from the surface to the top of the model atmosphere. At each point of the columnar sub-grid, four mixing ratio values are summed: ice mixing ratio, snow mixing ratio, rain mixing ratio, and cloud mixing ratio. If their sum meets or exceeds 0.001 g/kg the point is flagged as "cloud." A 0 value is designated for a non-cloud grid point and value of 1 is designated for a cloud grid point. The 0 and 1 values are averaged across the sub-grid at each vertical layer and converted to percentage. The percentages are classified as: 100%-89% is overcast, 51%-88% is broken, 39%-50% is scattered, 14%-38% is few, and 0%-13% is clear. Each cloud coverage type is assigned to its corresponding level, expressed in feet above mean sea level. Any overcast, broken, scattered, or few layers are grouped according to level for each location. As many as four cloud layers are reported for each location. If there are no overcast, broken, scattered, or few layers, the location will report 'SKC' (sky clear). The cloud layer reports are given in a form consistent with aviation weather reports, for example, an overcast layer from 5,000 ft to 10,000 ft is expressed as 'BKN/OVC 050/100' where the levels are expressed in hundreds of feet. For simplicity, broken and overcast layers are grouped into one designator and scattered and few layers are grouped into their own designator (FEW/SCT).

The cloud cross-section forecast layer products also rely on the same innermost COAMPS mesh. There are cloud cross-sections at five of the designated locations in the

western part of the range and along two routes that cross the range from west to east. Each location along the short and long routes are centered on a 5x5 set of profiles to form a corridor of values that correspond to the cloud layer text values. At each interpolated location along the cross-section route the profiles of four mixing ratio values are also summed. The average profile sum is contoured at 0.001 g/kg to define the visual edge of the cloud layer.

In addition to the continuous, hands-off products developed for use in the SOC, the processing of radar data, and subsequent products, has been another major accomplishment for Nowcast. Algorithms and software have also been adapted and improved for generating Nowcast products from the SWR data. The products include composite reflectivity (both single radar and mosaic), 3D reflectivity mosaic, single radar radial velocity, and VAD wind profile (see Fig. 7). Meanwhile, the quality-controlled level-II (3D) data from SWR are also fused with other sensor data for the ADAS 3D cloud analysis.

4.4 GIS PRODUCT DISTRIBUTION

In addition to the product distribution medium that is provided via a web page that continually updates and animates the forecast products, the Nowcast developers have also integrated a set of Geospatial Information Services (GIS) web services into the Nowcast system. An Open Geospatial Consortium (OGC) Web Map Service (WMS) was developed on a dedicated server and integrated with the Nowcast system to provide a common, accessible GIS interface to the Nowcast data products. The OGC is an international organization of commercial, government, and non-profit entities with the intent and purpose of developing common, open standards for the GIS community. The WMS standard from the OGC provides a common language for the sharing and distribution of GIS map image products over the Internet.

The addition of OGC WMS support to the Nowcast system ensures compatibility with a large number and wide variety of third-party commercial and open-source GIS clients. The Nowcast WMS server offers the Nowcast user the option to freely select and use any available OGC WMS client to query, select, and display Nowcast data product images. In addition, the WMS server provides the ability to fuse the Nowcast data product images with other geospatial information available from other sources.

The Nowcast OGC WMS server was successfully tested with the ArcGIS Desktop component of the DoD Commercial Joint Mapping Tool Kit (C/JMTK) software (Figure 10). The C/JMTK software suite is now the “standard geospatial exploitation tool for DoD C2I systems” (www.cjmtk.com). The ability to provide the Nowcast data to the C/JMTK system via a WMS service ensures that the Nowcast system will be able to co-exist and contribute with other DoD geospatial data services. The Nowcast WMS server was additionally tested with other third-party OGC WMS clients, such as UDig from Refractions Research and NASA’s WorldWind.

The Nowcast OGC WMS server was further enhanced with features such as dynamic cataloguing of data and multiple WMS version support (1.1.1 and 1.3.0). The server is capable of managing and processing a stream of live Nowcast and COAMPS forecast data. A standard Simple Object Access Protocol (SOAP) XML-based interface to the server was also developed which allows a web-services consumer to easily attach to the server and request products over the network using the ubiquitous HTTP web protocol. SOAP is a foundation component of web services, providing a basic messaging framework on which to build Internet applications and services.

With the importance of the time dimension when dealing with meteorological data, it was essential to provide a facility for the client to specify exact date and time parameters when querying the Nowcast WMS server. The OGC WMS standard provides an optional feature where a date and time can be specified in a query to a WMS server. Support for this OGC WMS time feature was added to the Nowcast WMS Server. Unfortunately, at this time, not all OGC WMS clients include built-in support for the WMS time feature. An alternative method for querying temporal data was necessary for these types of clients. The Nowcast WMS server was enhanced to allow dynamic time-stamping of layers which provides users with "non-time aware" WMS clients with a method to query for temporal data.

In addition to the WMS web map service, an OGC Web Feature Service (WFS) implementation was also developed for the Nowcast system. The WFS standard provides a common language for sharing and distributing geographical feature objects over the web. Unlike the WMS which offers pre-rendered images of data, the WFS offers the clients direct access to geographical data encoded in the Geography Markup Language (GML) standard. The GML data can then be further processed, if necessary, by the client. The GML data format standard enables a vendor neutral exchange of geospatial data.

Certain Nowcast data products were found to fit this type of distribution system. For example, METAR data observations consisting of several parameters at a certain latitude and longitude point would be useful to provide using WFS. A WFS client would have the ability to process the raw data into a more useful format. The raw data could also be archived and used for statistics, verification, etc.

Rather than developing a proprietary WFS implementation for the Nowcast system, it was decided to use existing, freely available open-source software to enhance the Nowcast system with OGC WFS support. Geoserver, a third-party open-source WFS server implementation, was selected to be integrated into the Nowcast system. Geoserver is the OGC reference implementation of the WFS standard. In addition to Geoserver, PostGIS, an open-source geospatial extension to the Postgres database, was integrated into the Nowcast system to provide the management and storage of observational data stored as geographical features.

The Nowcast WFS server provides observational data products in GML format. Any OGC WFS compatible client can be used to select, query, display and/or process

Nowcast observational data. The Nowcast WFS server was tested using an open-source third-party WFS client, UDig, from Refractions Research.

The Nowcast WMS and WFS services are powerful features that facilitate integration of the Nowcast products with many external, third party GIS client applications. The OGC standards are increasingly gaining popularity within the GIS industry and will eventually be supported by most or all GIS software applications within DoD. The addition of these services into the Nowcast system eases its compatibility with data product consumers. In addition, being that the major goal of the Nowcast system is data fusion and integration; the OGC services provide the necessary flexibility to allow a user to interactively and dynamically combine the different data products together within a single display.

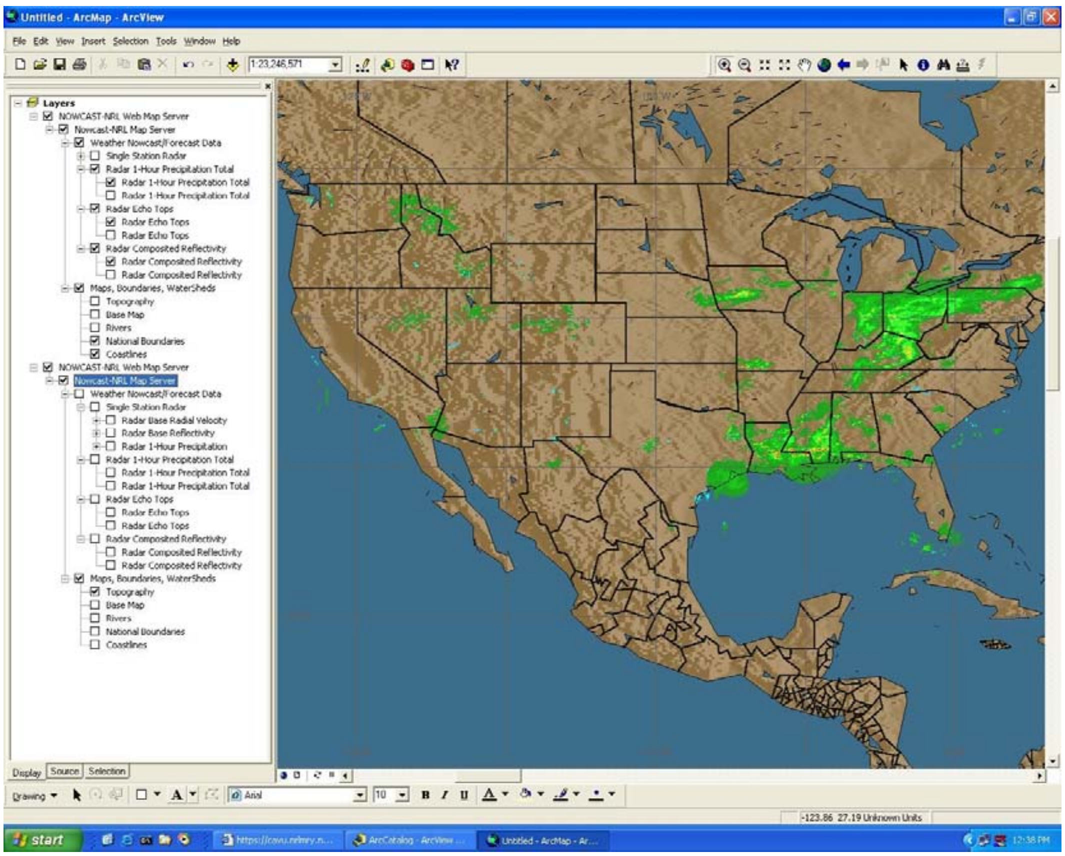

Fig. 10. Example screen shot of the ESRI commercial ArcMap GIS client, a component of C/JMTK, displaying Nowcast radar reflectivity data for the U.S.

4.5 <u>ARCHITECTURE</u>

All of the Information Technology (IT) components described above are built upon an IT architecture based on the J2EE (Java Enterprise Edition) platform that provides a modularity in the design and a commonality in the process communications. Nowcast is implemented as a suite of web server applications that communicate with each other using Java Message Service (JMS) to maintain state and share configuration information. Schematically, this architecture is shown in Figure 11 and this design is the result of a

refactoring of the original web-based design. The new system is much more scalable and efficient than the original system was.

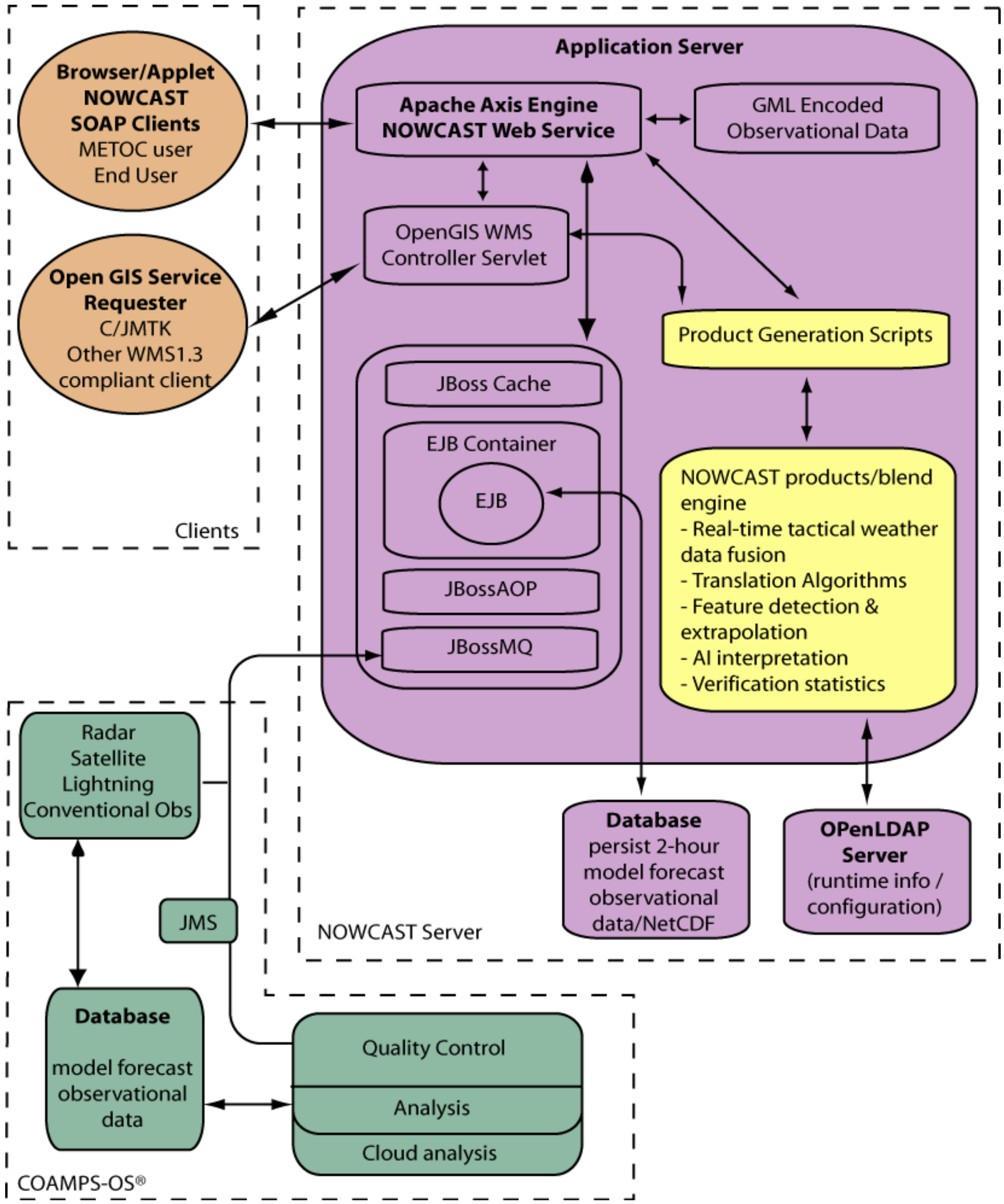

Fig. 11. Schematic diagram showing the Information Technology (IT) architecture of the Nowcast system including linkages between the Nowcast server, COAMPS-OS, GIS server, and client applications.

4.6 MEETINGS AND TRAVEL

4.6.1 Flag Level Briefings

April 1999, Commander, Cruiser Destroyer Group 3

September 1999, Naval Strike and Air Warfare Center
March 2000, Third Fleet
August 2000, Carrier Air Group Warfare Commanders Conference
December 2000, Oceanographer of the Navy
August 2002, Commander, Naval Meteorology and Oceanography Command
September 2002, Oceanographer of the Navy
September 2002, Naval Strike and Air Warfare Center

4.6.2 Integrated Product Team Meetings

July 2000
May 2001
June 2002

4.6.3 Demonstrations

July-August 2002, Fleet Battle Experiment - Juliet

4.6.4 Meetings

- January 17, 2003 at Naval Pacific METOC Center, San Diego to meet with Commanding Officer CAPT Ray Toll and Executive Officer CDR Scott Katz
- November 14, 2003 at Naval Postgraduate School (NPS)
- March 04, 2004 at Naval Research Laboratory (NRL)
- July 20-21, 2004 John Cook traveled to NAS Fallon to meet with Matt Young at NPMOD for introduction and training on the Nowcast system.
- August 17-18, 2004 John Cook, Shelley Potts, and Allen Zhao traveled to NAS Fallon to evaluate how the system is being used and to troubleshoot some local SWR radar issues.
- October 05-06, 2004 John Cook, Mike Frost, Paul Harasti, Shelley Potts, and Allen Zhao traveled to NAS Fallon for an RTP meeting with NPMOD, ONR, and Desert Research Institute (DRI).
- November 30-December 01, 2004 Gary Love and Shelley Potts traveled to NAS Fallon and DRI for discussions regarding procurement and installation of weather stations within the Fallon range training complex.
- February 15-16, 2005 Mike Frost and Paul Harasti traveled to NAS Fallon to investigate problems and implement solutions concerning the SWR scanning configuration, data processing and data transfer to NRL.
- March 18, 2005 Paul Harasti and Shelley Potts met with Tom Murphree of NPS to discuss verification of the Nowcast products and possible collaboration.
- March 29-30, 2005 Larry Phegley, Shelley Potts, and Sean Wells traveled to NAS Fallon to meet with Matt Young of NPMOD to discuss the latest developments and enhancements to the Nowcast system.
- November 15-16, 2005 John Cook, Mike Frost, Gary Love, and Shelley Potts traveled to NAS Fallon and DRI to discuss weather station installation and operation, view one site (B17), and to discuss with Naval Strike and Air Warfare Center (NSAWC)

the strategy for setting up the Nowcast display in the Strike Operation Command (SOC).

- January 23-25, 2006 John Cook traveled to NAS Fallon for installation of the Nowcast display in the SOC.
- February 13-14, 2006 Gary Love and Shelley Potts traveled to NAS Fallon to meet with Matt Young and LCDR Cantu to check up and view the Nowcast display in the SOC and to meet with current users of the products (blue shirt flight instructors) for feedback.

5. RESULTS

A major hurdle that prevented the use of Nowcast beyond NPMOD was the unavailability of the network pump at NRL Monterey to deliver the unclassified products to a classified network. The installation of an unclass-to-class transfer did not happen in the time scale of the RTP. However, to side step the issue, Nowcast developers provided an unclassified computer and large format monitor for use directly in the SOC at NSAWC. The continuously updated and animating forecast products are displayed 24-7 on the SOC floor using a web browser that refreshes every five minutes. This hands-off weather forecast products display is continuously available for training exercise planners and decision makers in the operational environment of the SOC.

5.1 NOWCAST FEEDBACK

ADM McGinn Ser J00/072 of 4 May 00
"I strongly endorse operational and financial support to assist the R&D efforts currently sponsored by ONR for the Nowcast Program."

ADM Nichols Ser 00/195 of 31 Jul 03
"… (NSAWC) supports installation of a prototype Nowcast system including validation sensors on the Fallon Range Training Complex …"

"Nowcast has potential to serve the Navy by enhancing warfighting decision-making and ensuring flight safety and mission effectiveness."

LCDR Alex Cantu and Matt Young, personal communication 2 Feb 05
"… my assessed value of Nowcast is it has a clear role in providing the critical environmental data necessary to meet the tight strike planning timelines associated with dynamic strike and close air support evolutions."

After the hands-free continuous product animations were deployed for operations at NSAWC, Nowcast developers solicited users for their feedback regarding which products are most used and which products prove the most useful. The following are their accounts.

Mr. Guy Bradley, NSAWC SOC

"I usually check for weather going over the passes but find the cloud layer forecast information [TAF text graphic] the most useful in supporting the Airwing (CVW) and Strike Fighter Advance Readiness Program (SFARP) training."

CDR Saunders, NSAWC Strike Department Head & Air Wing Overall Instructor
"The top down products (alpha-numeric cloud layers and alpha-numeric surface visibility) are the most useful. Cloud layer cross section displays aren't too useful; however, I like the vertical wind profile on the side of this type display. Surface wind forecast information isn't too useful either."

CDR Weber, NSAWC Operations Department Head & Air Wing Overall Instructor
"All products are useful. I particularly like the cloud layer cross section displays. I think the accuracy of the product needs to be verified so that the decision makers know how much trust to give NOWCAST. I recommend that pilot reports on cloudy days be used to verify the NOWCAST accuracy."

CDR Yates, NSAWC Air Wing Overall Instructor
"All products are useful. I particularly like the cloud layer cross section displays. As an overall instructor, I use the NOWCAST information to help make real-time decisions whether or not to delay or cancel an air wing event that is being impacted by the weather."

LCDR Bieber, NSAWC Air Wing Overall Instructor
"The cloud layer cross section displays are the most useful. Pictures provide the best situational awareness. Top down products (alpha-numeric cloud layers and alpha-numeric surface visibility) displays aren't too useful. The NOWCAST display gives a good heads up that the weather has turned bad or will soon be turning bad in the remote parts of the training range. This prompts me to make phone calls to get additional information and possibly need to make modifications to the planned event."

LCDR Hansen, NSAWC Air Wing Overall Instructor
"The top down products (alpha-numeric cloud layers and alpha-numeric surface visibility, and surface wind) displays are the most useful. However, I think the display (cloud cross section) is too high in resolution because I know that the models aren't that good. It might be better to smooth out the cloud layers. I like the NOWCAST display and would definitely rely on it if the products proved to be accurate."

The following is a response NOWCAST developers received when the service was interrupted to better allocate computer resources.

AG1, Scott M. Phillips, NAVPACMETOC DET LEMOORE NAS, CA
"I mainly use the cloud heights, visibility, and winds model data. We have a lot of F/A 18 pilots who fly missions to the Bravo ranges based here in Lemoore so any extra METOC help is always a welcomed necessity. Since finding the Bravo range website, I have found it much easier to give the pilots a detailed and accurate seeming forecast for these areas. I hope that this website will continue to stay working."

5.2 DISCUSSION OF SIGNIFICANT WEATHER CASES

During the 8-month period since the automated animations were installed in the SOC, nine major weather events have been observed in the Fallon Area-of-Operation (AOP) as identified in Figure 12. Three of the nine cases have been selected for discussion, with cases numbered 1, 2, and 3, in order of occurrence.

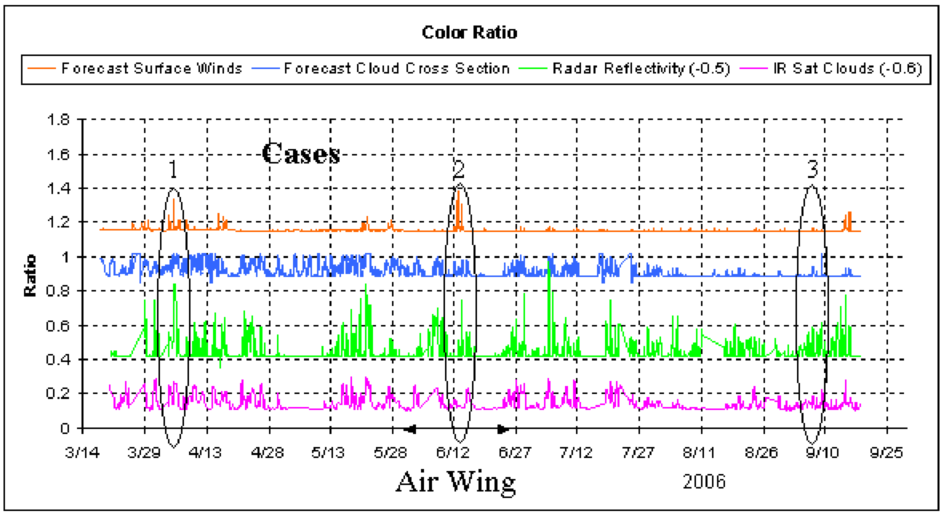

Fig. 12. Time line from March to September of forecast surface winds, forecast cloud cross section, radar reflectivity and IR satellite used to help identify cases 1, 2, and 3 of significant weather at Fallon. Each time series is a ratio of the areal extent of image colors to clear weather image colors, so spikes represent times of increased weather activity as depicted in the visual representation of the product. The time series have been artificially offset in the y-axis on plot to better visualize the relationships.

5.2.1 Case 1

April 3-8 2006, had several cycles of severe high winds in the high, mountainous elevations east of Fallon (over 9000 ft) that represent a major safety hazard. Four cycles of high wind speeds, in Figures 13a-d, occurred, with southerly winds from 03Z April 3 to 12Z April 4, southerly winds from 18Z April 4 to 08Z April 5, then westerly winds from 17Z to 16Z April 6, and finally southerly winds again from 17Z April 7 to 14Z April 8. All four cycles produced surface winds above 20 kt over large areas and westerly winds produced very strong down-slope winds north-east of Gabbs that exceeded 40 kt from 07Z to 12Z April 6. These wind events were not related to local thunderstorm activity, with few radar returns shown in the vicinity of the winds, but were due to mesoscale interactions with synoptic conditions from large storm systems south of Nevada (not shown). Although no missions were planned at the time, each wind event would have had significant impacts on helicopter operations and rescue missions.

5.2.2 Case 2

The June 11-15 2006 event occurred during Air Wing training and was very similar to Case 1. Again, severe high winds in the high, mountainous elevations east of Fallon formed in three distinct cycles, all southerly, although the last event ended with winds backing from the east. The first cycle in Figure 14a occurred 19Z June 11 to 03Z June 12, the second cycle from 17Z June 12 to 08Z June 13 (Figure 14b), and the third from 17Z June 13 to 10Z June 14 (Figure 14c) with the winds returning to normal speed about 00Z June 14. In this case very few clouds and radar returns were present. Surface winds were a major consideration during wing operations such that the COAMPS-OS wind forecasts played a substantial role in daily planning and conducting operations according to anecdotal evidence.

5.2.3 Case 3

September 6 and 7 2006, had two significant summer thunderstorm events over central Nevada that both started to evolve at 20Z (1 pm local) as shown in Figures 15a-d and impacted conditions on the Range. The intense radar activity of the September 7 storm is shown in Figures 15a and 15b which resulted in downburst wind forecasts. The winds in Figure 15c occurring at the EW-71 site represent a significant safety hazard for helicopter operations that typically occur there during exercise events. Figure 15d shows remarkable downburst events north and east of Gabbs that could prove disastrous for helicopter operations if not anticipated ahead of time. The down-flow must be quite strong to support the crescent-shaped 20 kt outflows over the two large areas.

In general, for all three cases, the forecast clouds along the two corridors relate well to the clouds in the IR satellite images along these corridors. One corridor was from the NAS to the rendezvous area known as Diamond; the other was from Diamond back to the target area at B17. The average cloud coverage in a map view for these three cases using the IR satellite images is 27% based on a visual estimate of cloud coverage of each image along the two corridors. A similar inspection of the vertical cloud cross-sections along these two corridors suggested a 42% average cloud coverage. The percentage of cloud coverage was estimated along each corridor in the IR satellite image to obtain the 27% average. Similarly the percentage of cloud coverage was estimated along each cross section using a horizontal percentage of a vertical integral to obtain the 42% average. This visual assessment provided 126 paired image comparisons that resulted in a 62% agreement between the IR clouds and the forecast clouds. If similar segments along the corridors were either clear or cloudy, they were assessed as agreeing. Since these comparisons would agree by chance only 11% (=27%x42%) of the time, the 62% correspondence is over five and a half times (62%/11%) better than chance. Although point forecasts of clouds may not agree with a specific satellite image, the general agreement and high correspondence verifies the skill of the COAMPS cloud forecasts at this scale.

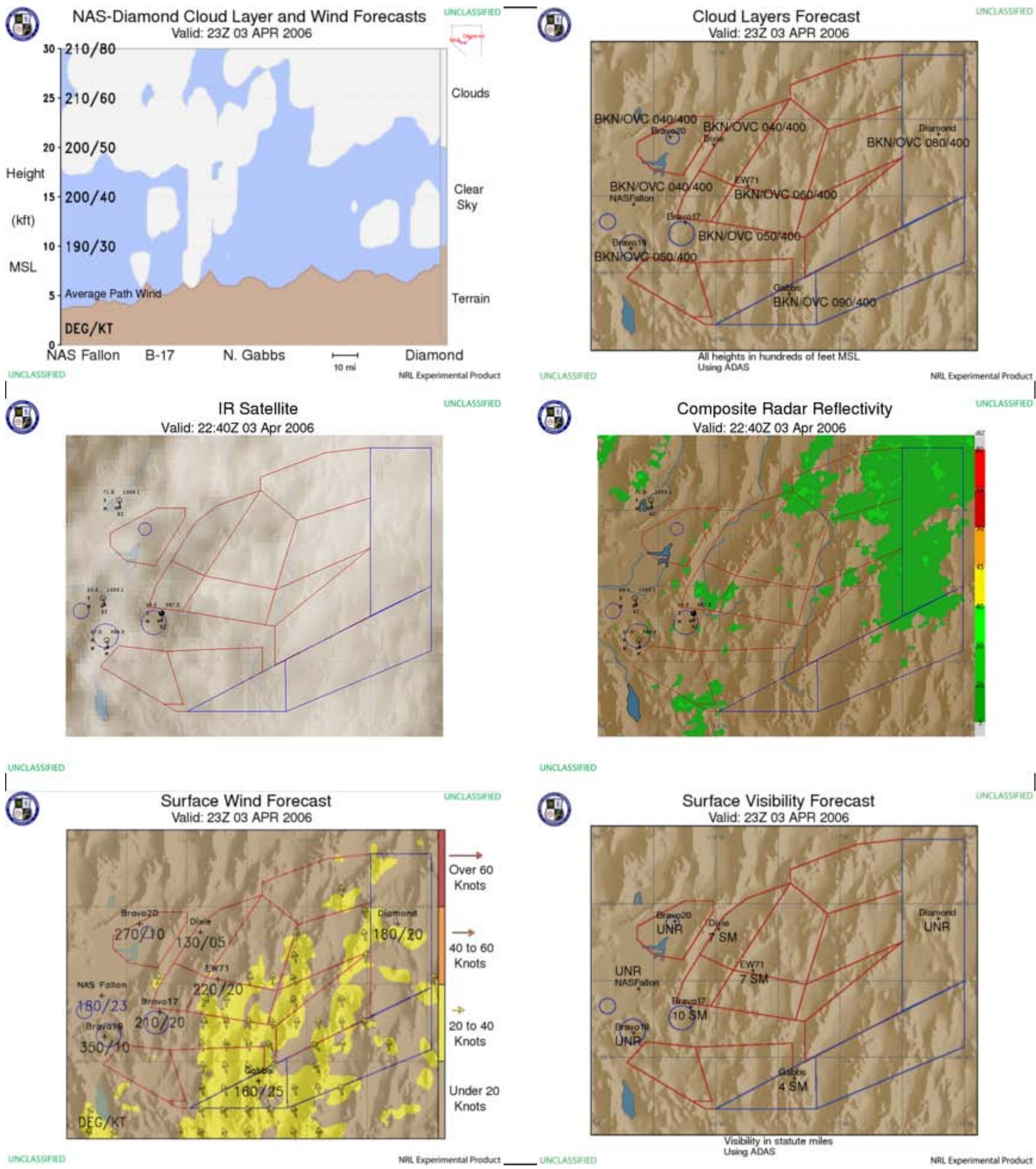

Fig. 13a. Case 1, 23Z 3 April 2006, high surface wind speed case – day 1.

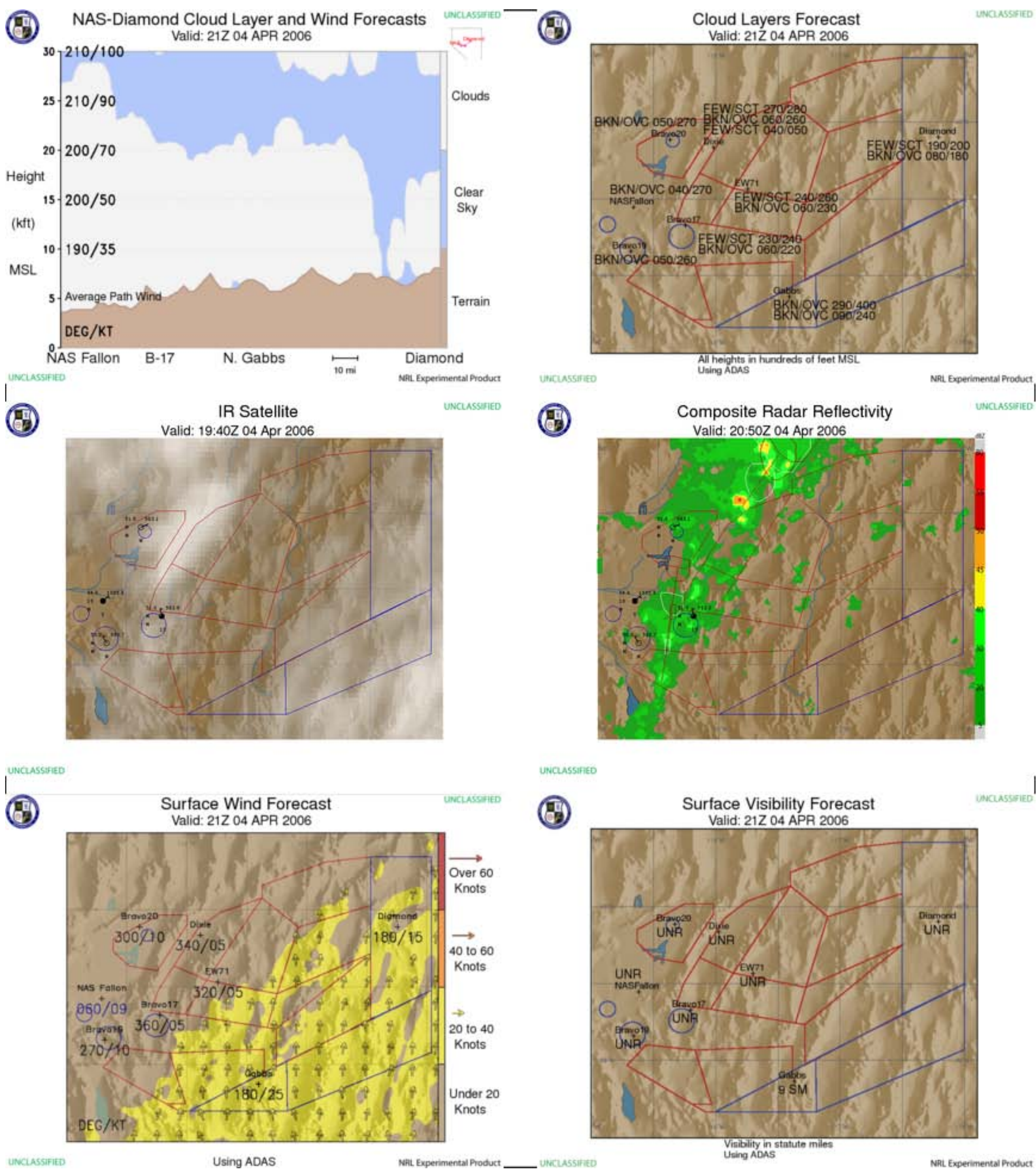

Fig. 13b. Case 1, 21Z 4 April 2006, high surface wind speed case – day 2.

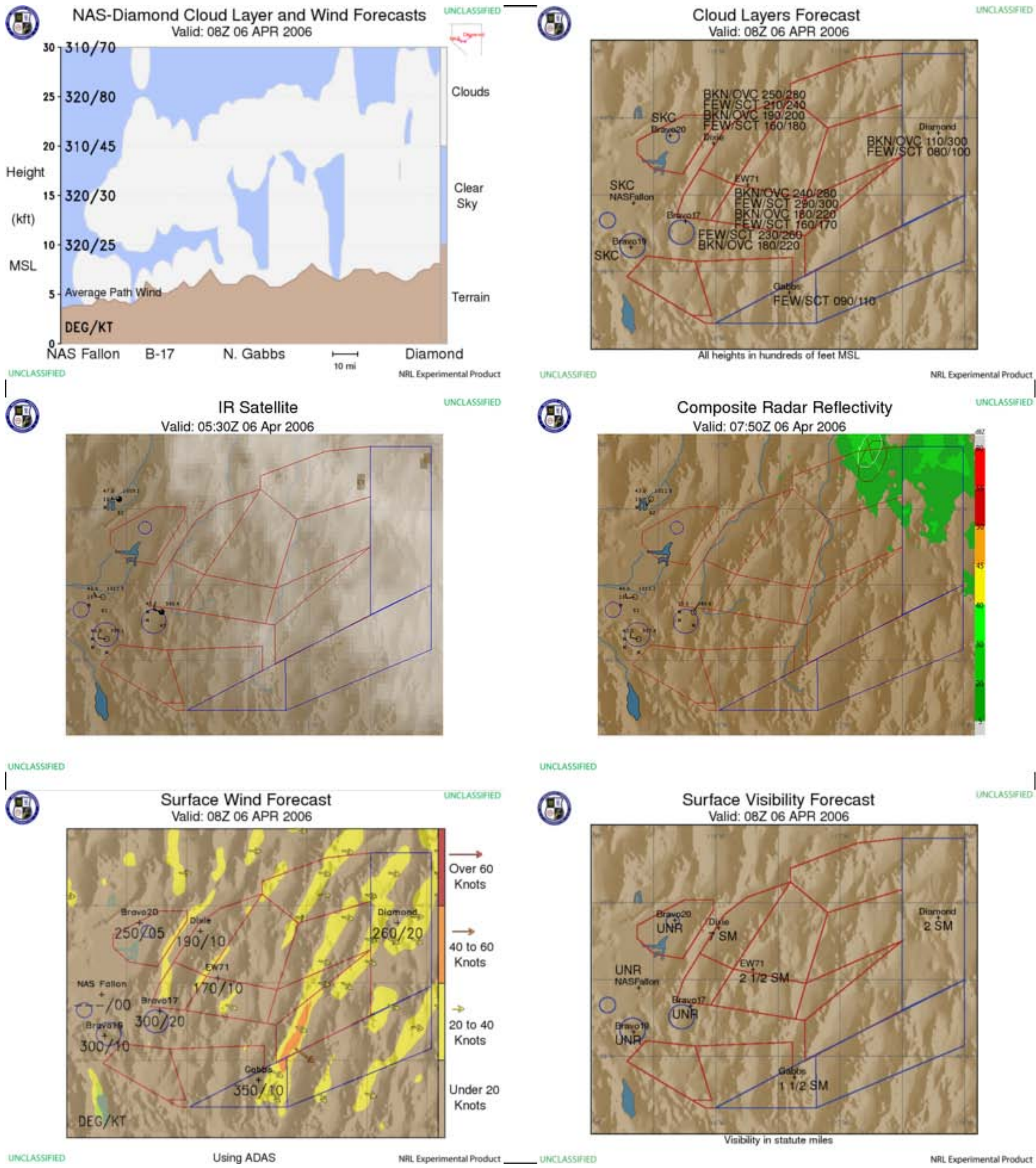

Fig. 13c. Case 1, 08Z 6 April 2006, high surface wind speed case – day 4.

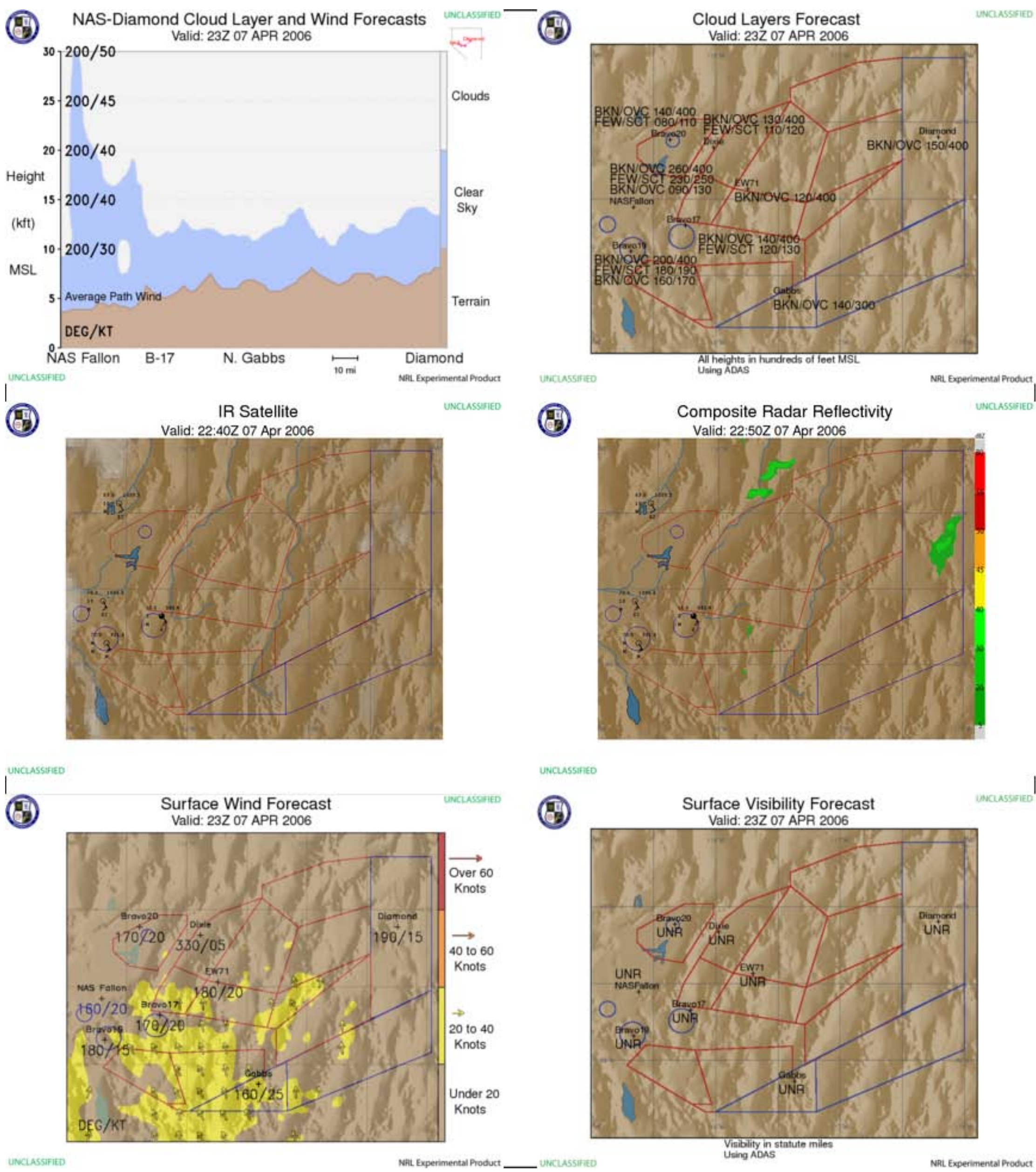

Fig. 13d. Case 1, 23Z 7 April 2006, high surface wind speed case – day 5.

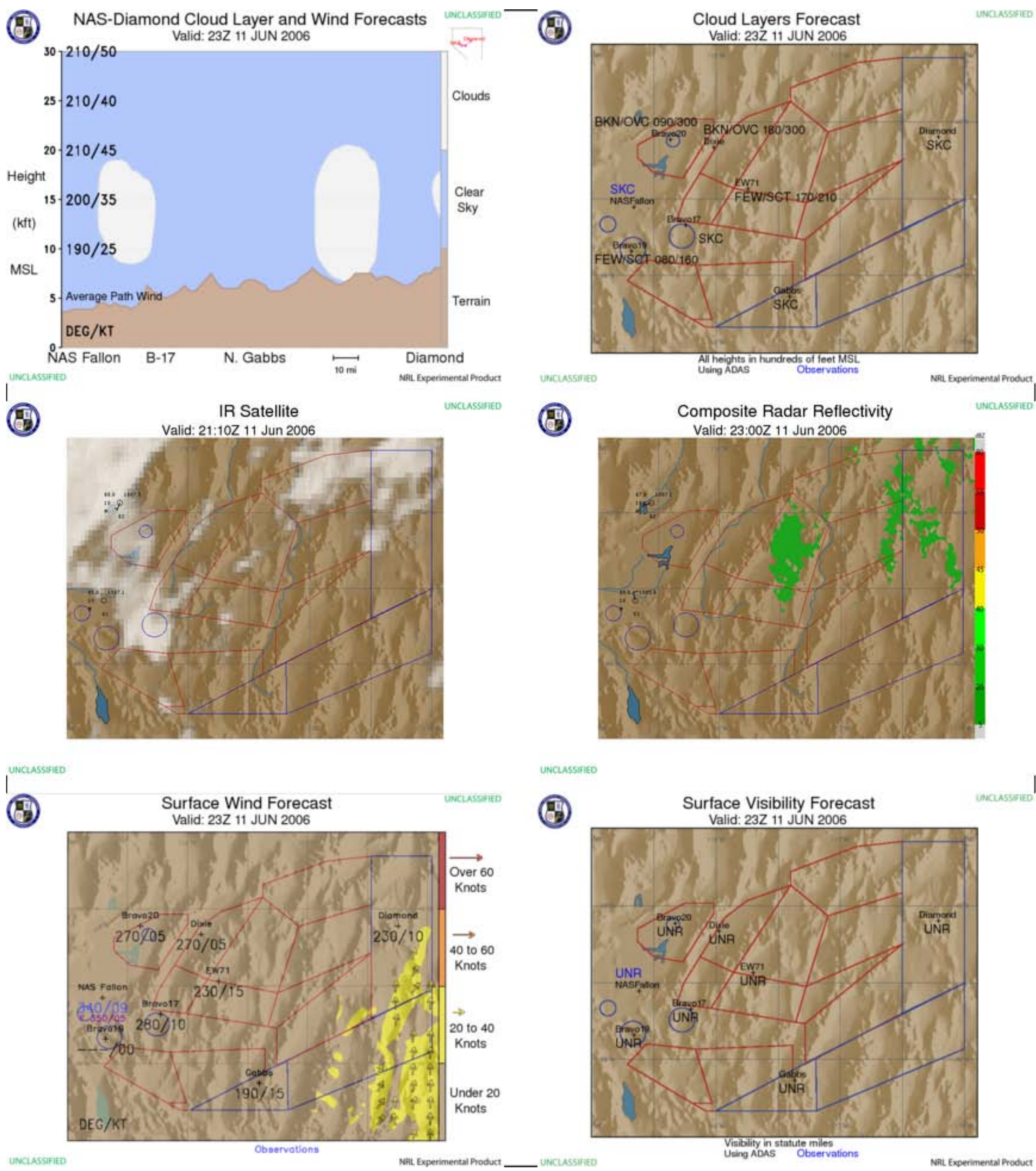

Fig. 14a. Case 2, 23Z 11 June 2006, high surface wind speed case – day 1.

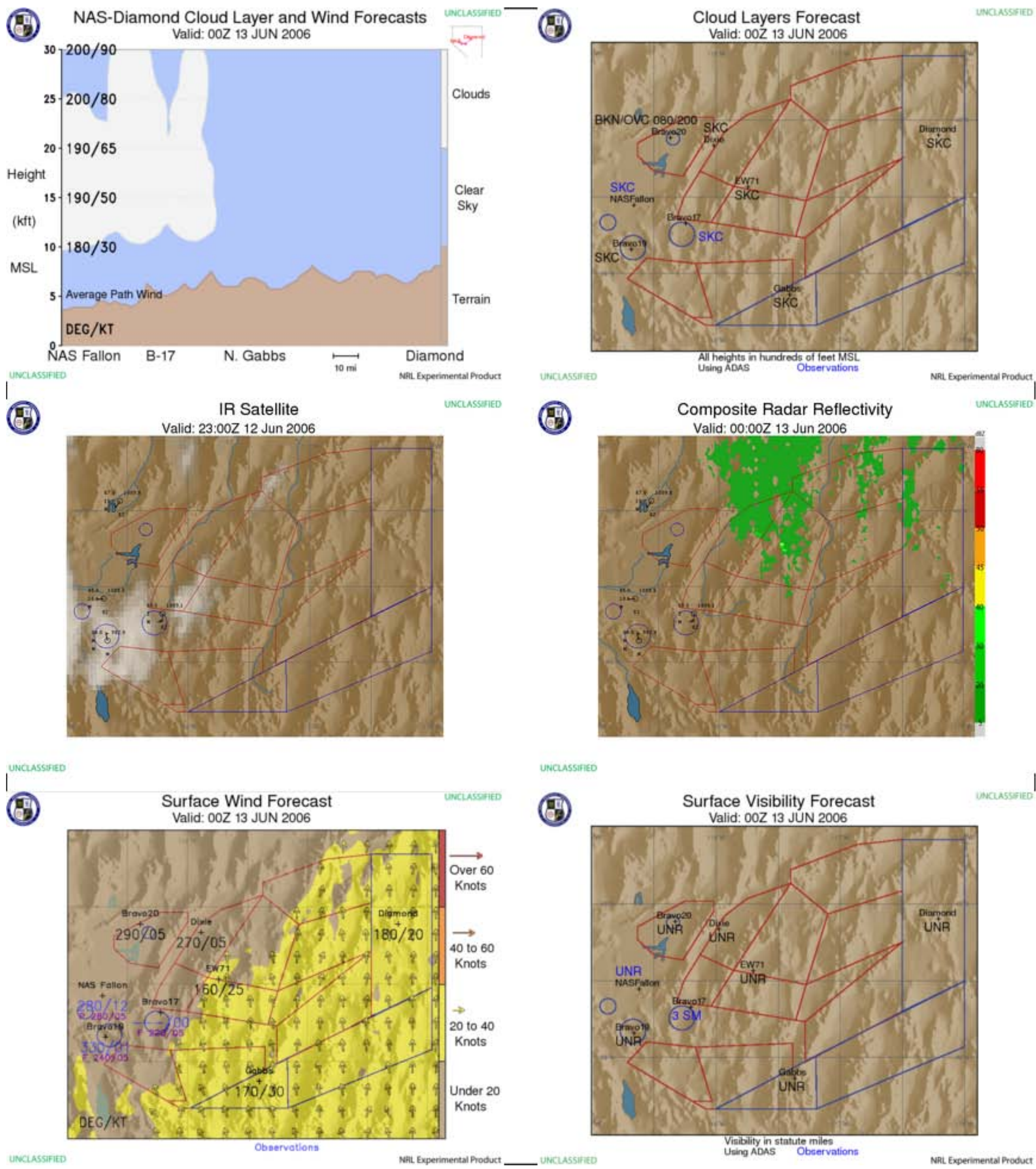

Fig. 14b. Case 2, 00Z 13 June 2006, high surface wind speed case – day 3.

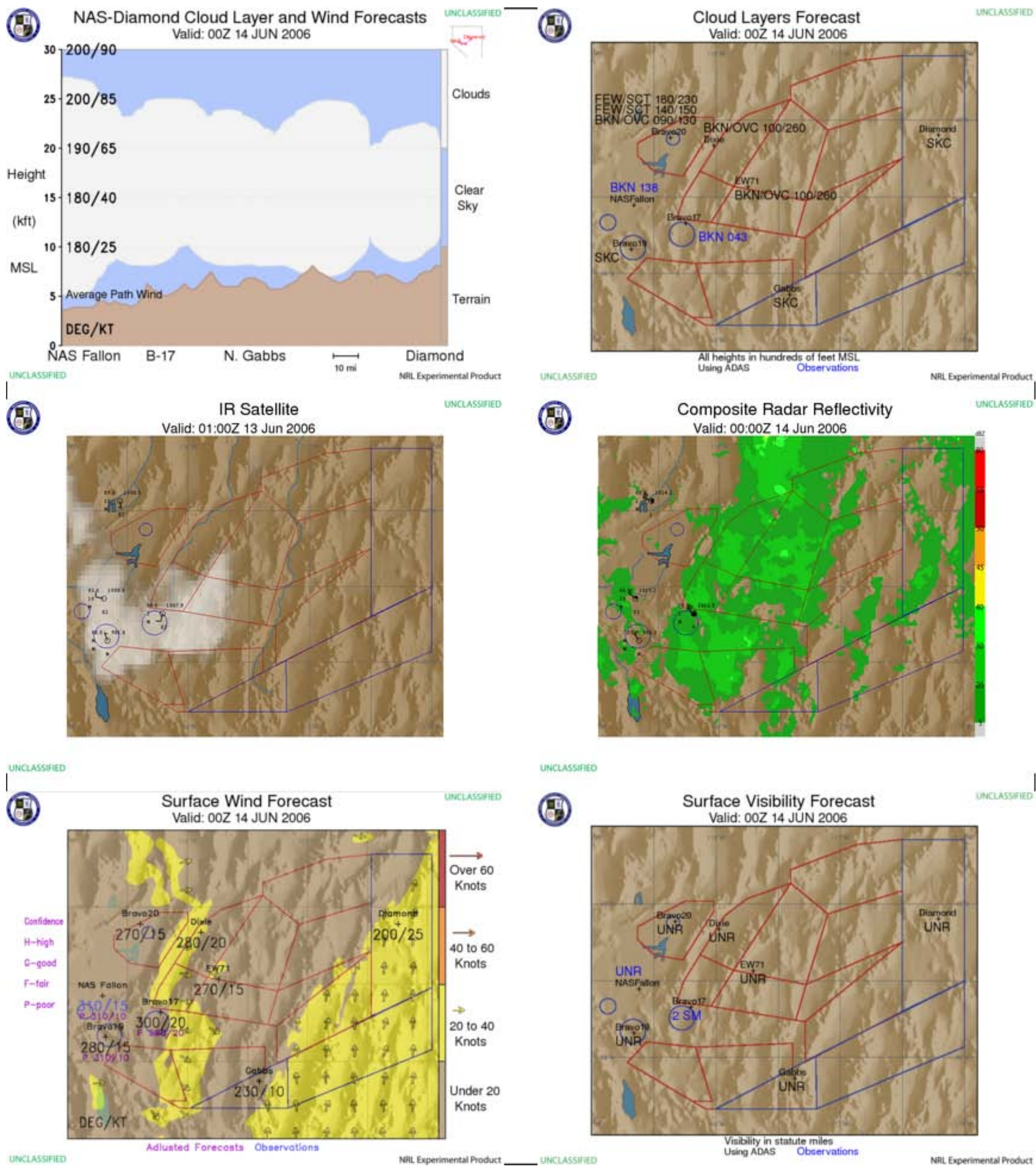

Fig. 14c. Case 2, 00Z 14 June 2006, high surface wind speed case – day 4.

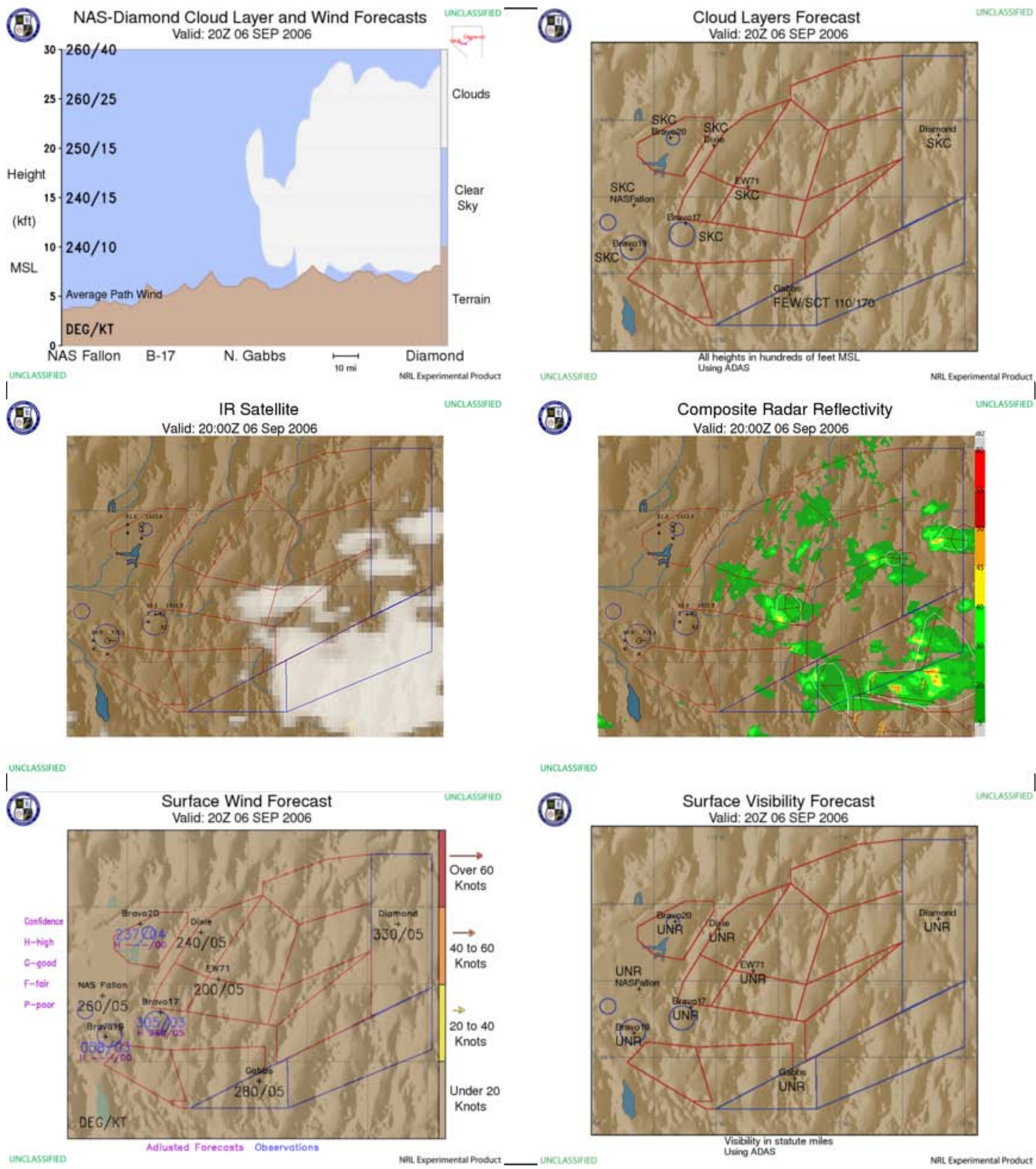

Fig. 15a. Case 3, 20Z 6 September 2006, thunderstorm case – day 1.

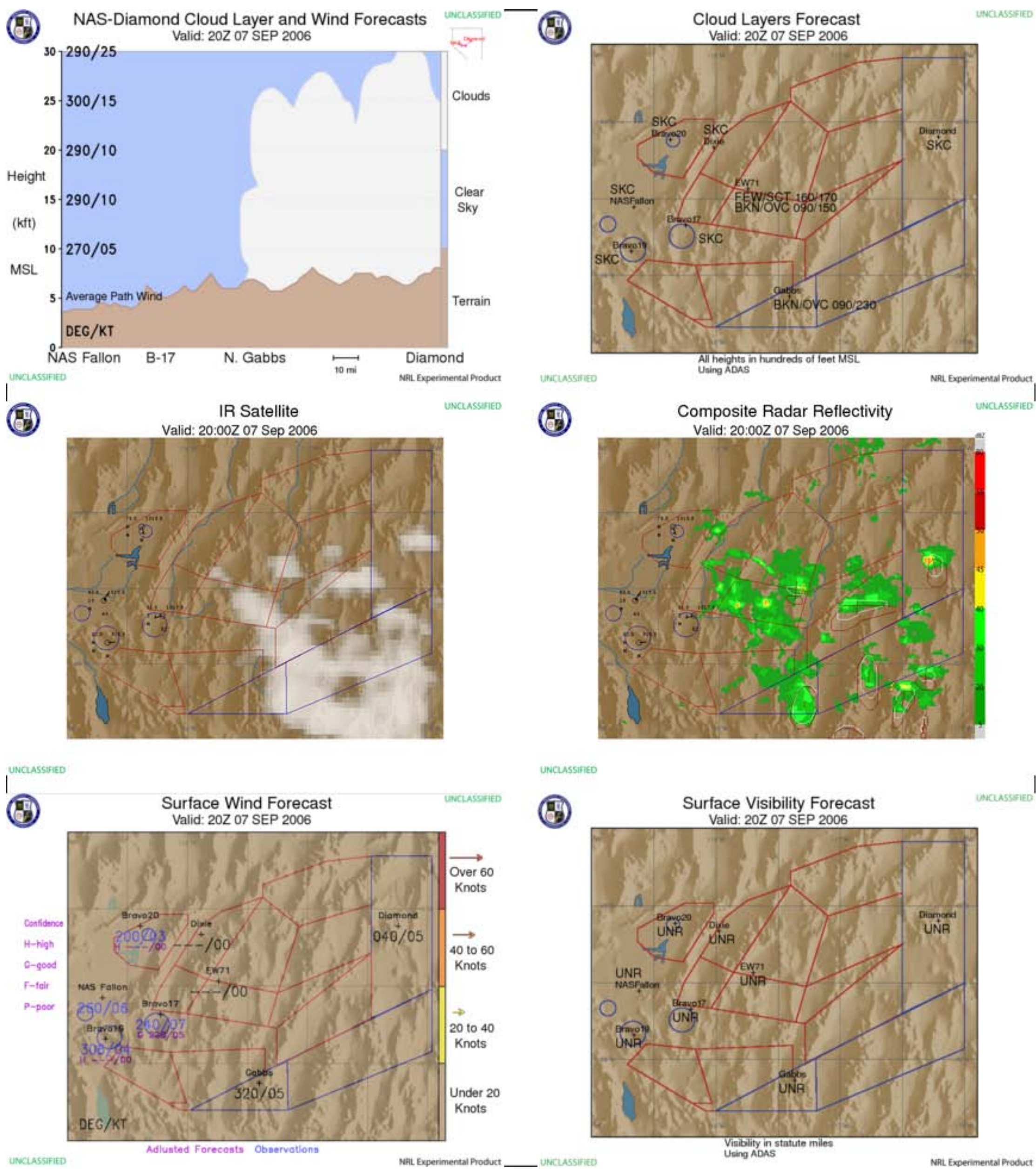

Fig. 15b. Case 3, 20Z 7 September 2006, thunderstorm case – day 2.

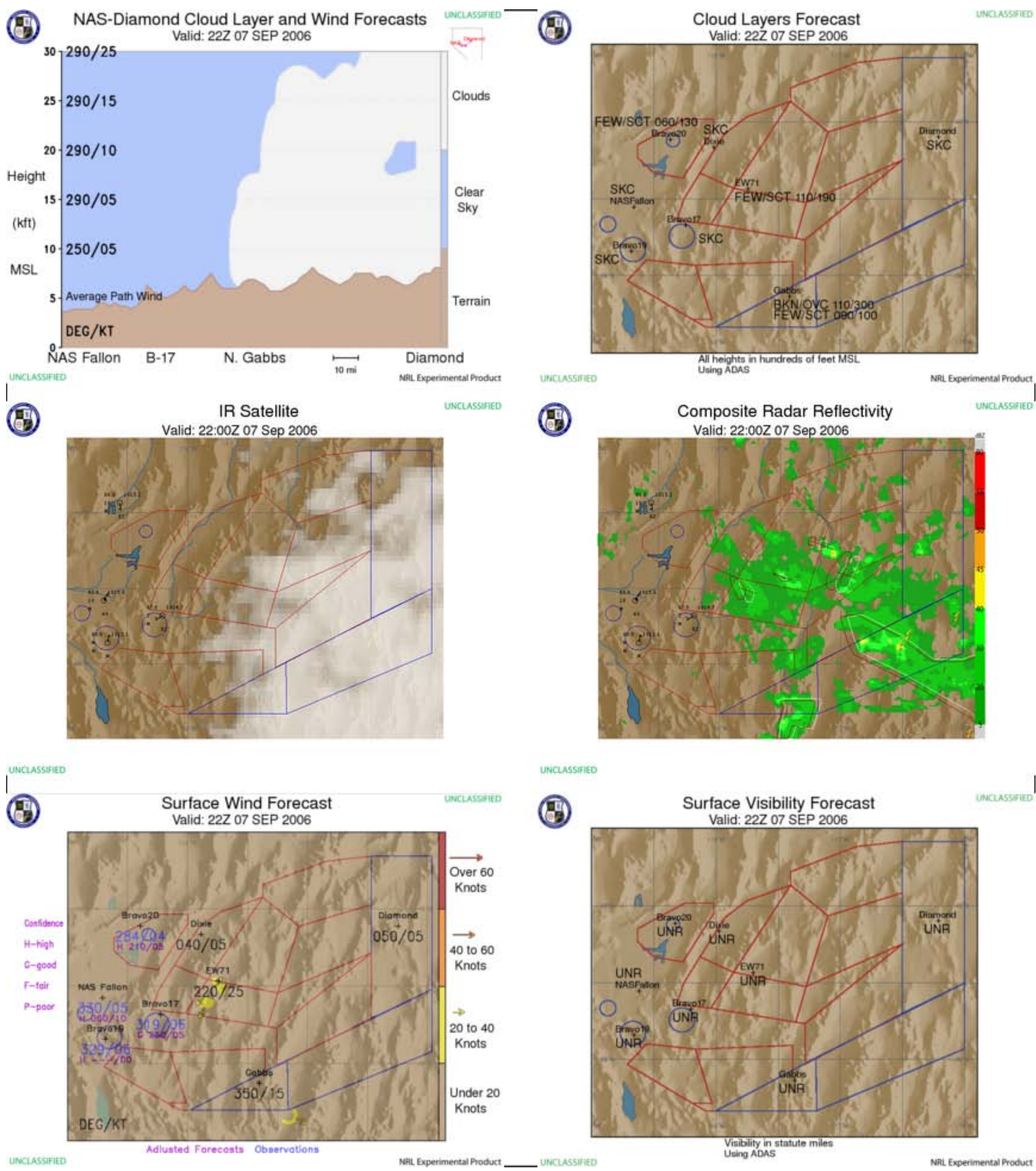

Fig. 15c. Case 3, 22Z 7 September 2006, thunderstorm case with downburst at EW-71.

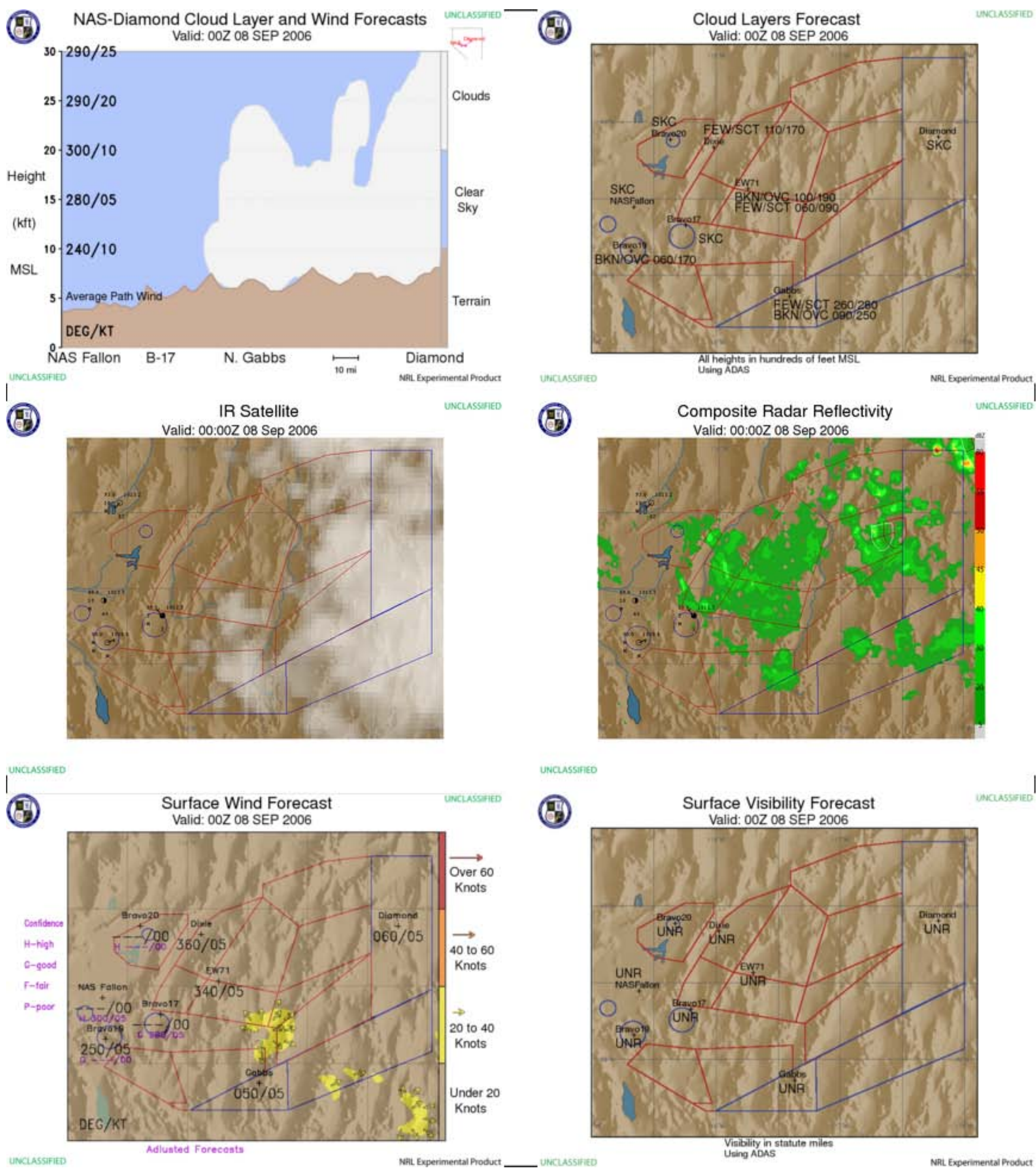

Fig. 15d. Case 3, 00Z 8 September 2006, thunderstorm case with downburst at Gabbs.

5.3 LESSONS LEARNED

A main motivator for the Nowcast project was to develop a forecasting tool that would integrate and fuse together many different data displays into one easy to use web accessible interface. While it is an efficient idea in concept, the Nowcast developers did not succeed in making the "one-stop" forecast tool a standard reference for METOC personnel at NPMOD. While the METOC personnel appreciated what the software provided, it became too difficult to break them out of their normal routines and habits. The forecasters were trained on referencing different tools for different forecast data. Furthermore, because the detachment runs on NMCI, the Nowcast applet was not available at most terminals. Nowcast is available on the NMCI S&T seats, of which there are only two in that office. Also, user login and authentication proved to be a cumbersome step users were not willing to pass through. Even the NMCI S&T seats would not support continuous viewing of Nowcast because the browsers timed-out and had no capability to override the time-out. These lessons proved helpful in developing the generation of Nowcast presently running in support of the SOC. The theme is the simpler the better; the less user interaction and user choice, the better. Once the user freedoms were restricted and the products were available to both forecasters and aviators, Nowcast began to be used routinely.

Many problems were overcome in the development and implementation of the Nowcast system for Fallon. In particular, acquiring, debugging, and using the local SWR data was a major challenge that is being successfully met. The SWR digital signal processor (DSP) or EDGE software is incorrectly scaling the radial velocity data gathered in the dual-PRF 4:3 scan mode, which was implemented to increase the maximum winds detectable by the SWR. The radial velocity data recorded in the UF files appear to be smaller by exactly a factor of three. This bias seems to be only a problem in the data stored in the UF files themselves since the EGDE software displays the correct radial velocity and VAD winds at KNFL, according to KNFL staff. It is therefore likely that the error is occurring in the part of the EDGE software that scales the data before it creates the UF files; perhaps the software is not accessing the correct information about the Nyquist velocity from elsewhere in the EDGE software or from the DSP. At this point, the bias can only be, and has been, corrected in NRL's SWR processing and quality control software for Nowcast. Since Nowcast developers do not have access to the source code for the DSP or EDGE created by Enterprise Electronics Corporation (EEC) for the SWR, 1) software engineers at EEC will need to be notified of this problem so that future builds of their DSP and/or EDGE can be corrected accordingly, and 2) the exact value of this bias can only be a best guess based on two factors. The first factor was the observation of smaller-than-expected radial velocities and VAD winds for the SWR as viewed on Nowcast. Figures 16 and 17 show, respectively, some of the data that were used to first identify the problem then later verify that the problem was corrected satisfactorily on Nowcast. The second factor was based on a logical deduction: The Nyquist velocity resulting from the dual-PRF 4:3 scan mode is exactly three times larger than the Nyquist velocity that would be available using a single PRF scan mode whose PRF is the lower PRF of the dual-PRF 4:3 mode. If the EDGE software is using this smaller Nyquist velocity to scale the radial velocity data stored in the UF files instead of

the correct Nyquist velocity that is three times larger, then that would be the source of the problem. The investigation demonstrated by the data shown in Figures 16 and 17, and other data comparisons since then (e.g., Figure 8), suggest that a factor of three is indeed a reasonable estimate of the bias correction factor (and likely exact). A report was filed electronically with the appropriate personnel at SPAWAR requesting that the error in the EEC software used by the SWR be investigated and corrected for this problem.

The SWR spectrum width data were found to be unusually large; very few, or no spectrum widths were found under 1 m/s compared to those typically found associated with ground clutter in other Doppler radar data (e.g., WSR-88D). For example, comparing the regions of ground clutter in the reflectivity and spectrum width echoes shown in Figure 6, there are no spectrum width values under 1 m/s, and many values greater than 3 m/s. This is very unusual for targets that are not moving and suggests that the SWR spectrum width values are biased. A possible bias similar to the radial velocity (a factor of three) was investigated but shown to be unlikely since, in this case, the true value of spectrum width is expected to be smaller, not larger, as was the case with radial velocity. Therefore, some other source of bias is the cause. An additional report has been filed electronically with SPAWAR requesting that the source of the spectrum width bias in the SWR DSP or EDGE software be investigated. The ability of radar data quality control algorithms to remove non-meteorological echoes in SWR and other DoD weather radar data in the future will be very limited for those algorithms requiring spectrum width data unless the source of this bias is identified and removed.

This project demonstrated that Nowcast data fusion is also a valuable tool to quality control not only products shown on Nowcast itself (e.g., identifying incorrectly-placed NIDS VAD winds in Figure 16) but also sensors that are important to the end user (e.g., identifying the bias in the SWR radial velocity and VAD winds shown in Figure 16, and identifying the SWR alignment problem shown in Figure 18 via the ground clutter filter on Nowcast).

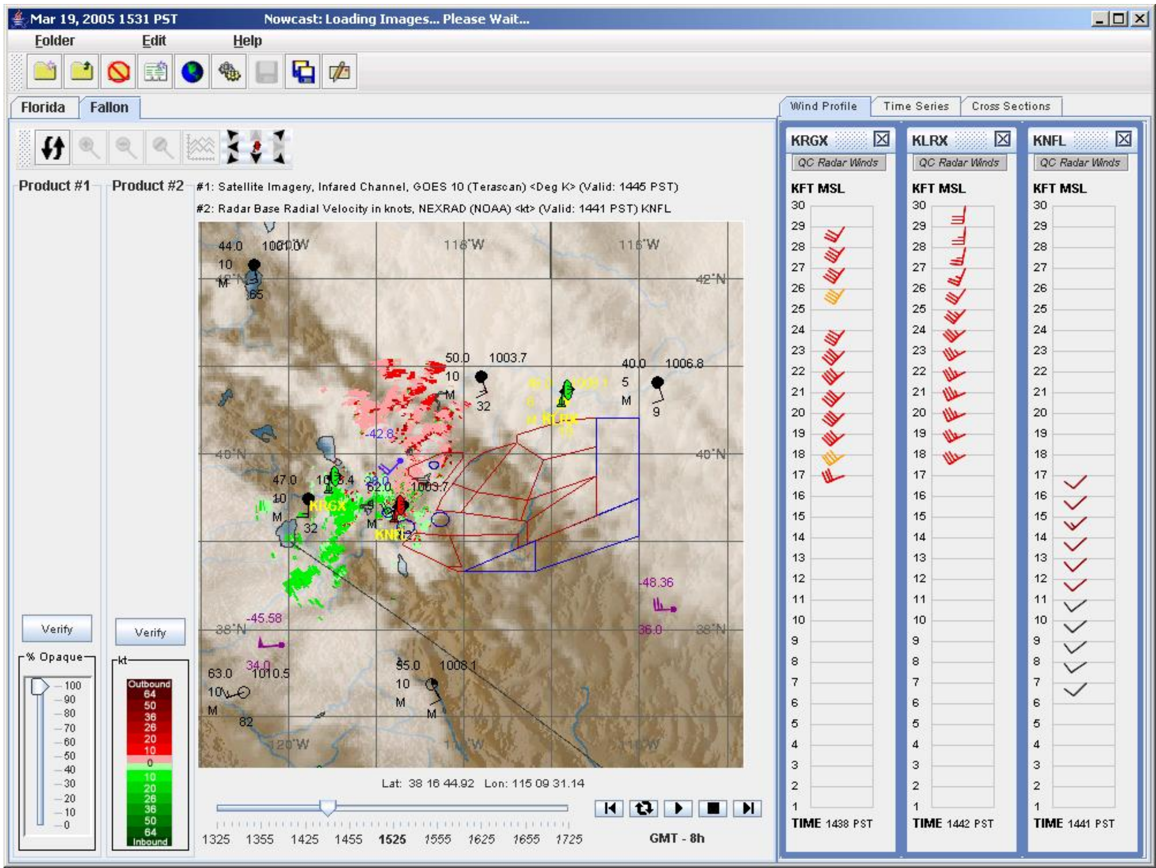

Fig. 16. Example of identifying problems with Nowcast products and end-user sensors. The Nowcast display shows the Fallon range with satellite infrared imagery, the fourth-tilt base velocity (1.9°), neighboring surface observations in black, and aircraft wind barb data in blue and purple (with temperature at top; altitude at bottom). A previously undetected problem with the placement of the WSR-88D VAD winds received from NIDS, in this case for the KRGX and KLRX, was readily identified from this Nowcast example. The high elevation of KRGX (8.4 KFT) and KLRX (6.8 KFT) made the problem more obvious than previous Nowcast demonstration domains at elevations closer to sea level. All VAD wind estimates for KRGX and KLRX had never appeared at lower altitudes than those shown in this example, and in a few other examples (not shown), which was unphysical based on precipitation echo clearly visible near the ground. It was concluded from this, and subsequently verified by software investigation, that VAD winds shown on Nowcast needed to be shifted lower in altitude by an amount equal to the site's elevation. With this downward shift in the KRGX and KLRX VAD winds, one can clearly see that the KNFL VAD winds are too small by approximately a factor of three (allowing for some wind variation across the domain). Comparing the KRGX and KLRX radial velocity data shown on Nowcast with that of KNFL (not shown) also suggested the KNFL radial velocity data were too small by a factor of three. Moreover, the aircraft data shown in blue indicate winds of 20 kt at 28 KFT, which is an altitude near the outer-reaches of the KNFL radial velocity data shown where radial velocities near or less than 10 kt are only visible, thus indicating a likely underestimate of the radial velocity by a factor somewhere between two and four. All of these Nowcast observations led to the conclusion that the SWR radial velocity estimates were biased, likely by a factor of three.

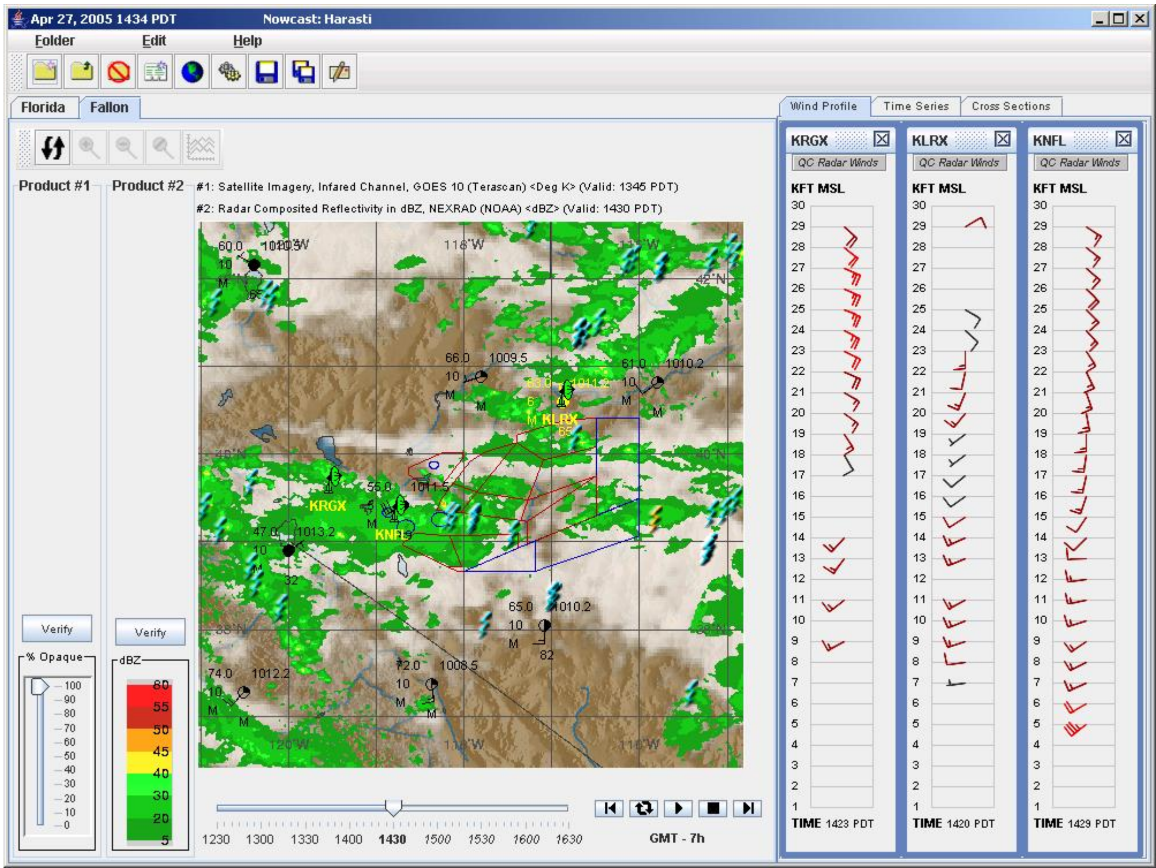

Fig. 17. A Nowcast example later than that displayed in Fig. 5 showing that the problems with both the placement of the NIDS VAD winds and the bias in the SWR radial velocity and VAD winds were successfully corrected. Note that the near-surface KNFL VAD winds at 5 KFT agree well with the surface wind observation taken at KNFL near this time, and also note the general agreement of all the VAD winds, allowing for directional wind shear across the domain. This example also shows another example of lightning data displayed on Nowcast. The locations of observed lightning are indicated by lighting bolt symbols superimposed on composite reflectivity data; blue bolts represent cloud-to-cloud lightning and yellow bolts represent cloud-to-ground lightning. Infrared satellite imagery is shown in the background.

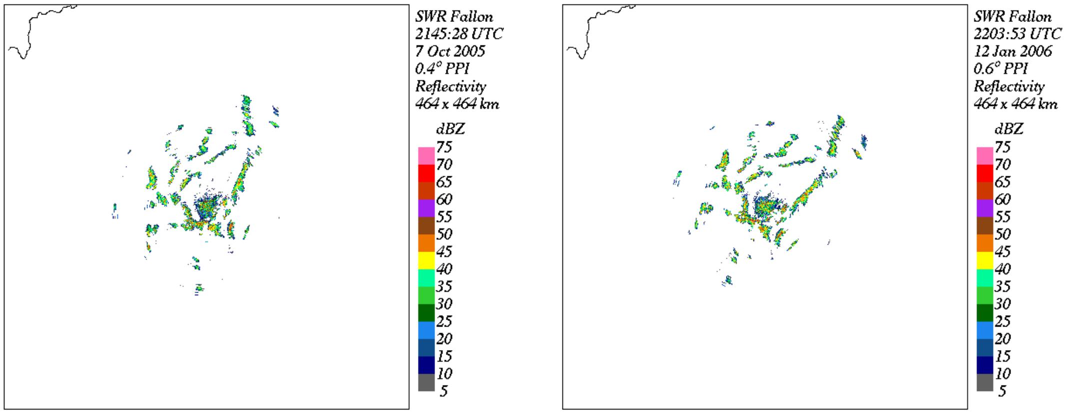

Fig. 18. Example of the identification and trouble shooting of a temporary SWR misalignment problem. Note the 30° clockwise rotation of the ground clutter echo returns from the nearby mountain ranges on these two different dates. Without the SWR ground clutter filter in place for the Fallon region on Nowcast, which was calibrated for the correct mountain echo returns shown in the left image and thus did not work for the case shown in the right image, this misalignment problem may not have been recognized at all on the EDGE radar display at KNFL. NRL notified KNFL of the problem and helped to re-align the radar correctly, using both new images and the ground clutter filter results on Nowcast as a guide.

6. FUTURE WORK

Nowcast is a network-centric data-fusion system that uses Enterprise Java technology to continuously update a local environmental database, access Coupled Ocean Atmosphere Mesoscale Prediction System – On Scene (COAMPS-OS) model data, and send fused products to end users via a web browser, allowing war-fighters to automatically maintain a common, relevant picture of the three-dimensional battlespace environment.

This environmental multi-source information fusion, data assimilation, forecast, and nowcast technology should be transitioned in the context of a dedicated capability to support U.S. Army and Marine Corps operations in Iraq and Afghanistan with up-to-date, high resolution, high fidelity environmental mission impact parameters through a portfolio of geospatial information web services available in a net-centric environment using reach-back mode. This concept increases net-centric capability for existing systems and does not require fielding of new sensors - rather the proposed system will take advantage of available environmental data, including data derived from through-the-sensor technology to extract the environmental signal from tactical sensor data, fuse multiple sensor inputs together in near real-time, providing derived, network-accessible products based on the fused information. A unique aspect of this concept is that all services can access a portfolio of web services and products from a common data store composed of environmental data collected from all services, thus ensuring common environmental situational awareness.

Work should continue on the development of an enhanced capability to assess the battlespace environmental conditions in the context of four-dimensional (4D) situational

awareness using both weather and ocean data and model predictions, including high-resolution terrain and bathymetric conditions. Rapidly updated 4D environmental data grids "corrected" on the fly to reflect the most recent in situ and remotely sensed meteorological and oceanographic observations available in the tactical environment would provide our forces with unprecedented spatial and temporal resolution environmental gridded data.

Other applications may benefit from such information. By using the proposed fused weather gridded database across the METOC domain, an Unmanned Aerial Vehicle (UAV) TDA could produce visualizations and data to support UAV operators and decision makers with predictions of mission-tailored forecast parameters. The Army plans to integrate spatial/temporal forecast databases with UAV mission profiles to depict weather impacts along the proposed flight path, and automate route optimization to provide the "best route" to exploit favorable current and forecast weather and avoid hazardous weather conditions. Additionally, the TDA will include target approach decision aid technology such as Target Acquisition Weapons Software (TAWS) and Infrared Target-scene Simulation Software (IRTSS) for target area probability of detection and sensor detection range values. This technology may prove useful for USMC support as well when shared with the Navy as part of this proposal.

The output from a Nowcast system may be the input to a very fine scale diagnostic model that can provide detailed wind information for urban and complex terrain domains. The Army Research laboratory (ARL) has developed and tested a preliminary version of its Three Dimensional Wind Field (3DWF) model that can provide an analysis of the mean wind field within an urban domain or over complex terrain. Typical horizontal resolutions are on the order of ten to a hundred meters and several meters in the vertical. The 3DWF runs in less than 5 minutes for a domain of about 2 x 2 km at horizontal resolutions near 10 m. The present work could accelerate the further development and testing of the 3DWF by providing NRL Nowcast system as an integral model that will allow the 3DWF to be ready for fielding within two years. This capability would give the Army and Marines a common capability to estimate the wind field at very high resolutions within the urban battlefield.

Decision aids hosted on a personal digital assistant (PDA) could provide an initial capability to determine environmental effects at lower echelons. Due to limitations related to reach-back capabilities of tactical PDAs to a remote environmental server, this initial set of applications will consist of standalone products that can be run with locally obtained data or extracted from the NRL Nowcast. These products will consist of a mobile heat stress decision aid (developed in conjunction with U.S. Army Research Institute of Environmental Medicine (USARIEM)) that will provide impacts of heat on soldier performance, to include probability of heat stress casualties, work/rest cycles, maximum work times and water intake requirements as a function of work rate and clothing level. A second application could consist of an accelerated upgrade to software for computing artillery meteorological messages (a computer met message - METCM and a ballistic met message - METB). The current version of this latter ARL developed

product is being fielded by the USMC for use in OIF and elsewhere. These messages can be used as input to other software to determine met effects on artillery round trajectories.

In a parallel development to the Army and Navy nowcast development efforts, a combination of Human Factors and METOC scientists, supported by ONR, have developed a family of net-centric web services capable of producing environmental mission effects spreadsheets and map overlays based on mission/platform/sensor criterion and the predicted environmental conditions from COAMPS, Nowcast, and other models, with the concept derived from cognitive analysis. This environmental visualization (EVIS) capability has been interfaced to the operational models at FNMOC and it has been evaluated by the U.S. Army V Corps in Iraq as part of the Assistant Secretary of Defense for Networks and Information Integration (ASD/NII) Horizontal Fusion initiative. Horizontal Fusion is a recognized early adopter of the NetCentric Enterprise Services (NCES) that integrates technology and operations to achieve "Power to the Edge" via the Global Information Grid (GIG) by providing tools and means to integrate the smart pull of data with expert interpretations of the information. EVIS products are available to all services throughout Iraq through the FNMOC Operational Enterprise Portal (OEP).

A major operational issue is to provide METOC products in compliance with recently adopted Geospatial Information System (GIS) standards, for example the open standards ratified by the Open GIS Consortium (OGC) and those of the Commercial/Joint Mapping Toolkit (CJMTK), using an information network such as the GIG. Use of the GIG and GIS standards allows METOC products to interface with the common operational picture, enhancing the joint, shared real-time situational awareness of battlefield forces and fostering increased interoperability and efficiency within a net-centric command and control framework. In response to the war fighter's need for more complete situational awareness, including the environmental situation, the COAMPS-OS/Nowcast system has been designed to gather and fuse available information, rapidly update products, and continuously provide a web-based high resolution depiction of the current METOC situation over the network, including derived products tailored to the end-user's mission using EVIS.

Battlespace environmental situational awareness is needed at different levels of application, e.g., for overall mission planning but also for focused tactical mission support. Focused tactical mission support will involve not only pre-mission planning aspects but also support to dynamic, real-time mission execution. With the current agile and creative adversarial threats, localized tactical Intelligence, Surveillance, and Reconnaissance (ISR) asset support is a very desirable mission support function. One way in which such support can be accomplished is via UAV systems that have multi-modal sensing capability and that may also have weaponry capability. These UAV systems require environmental support for both flight worthiness and optimization of sensing contexts, thus they need to be informed of and must be able to deal with the localized dynamic weather environment. An example is UAV system support to USMC convoy operations where timely and focused ISR is needed both along the on-road and off-road paths the convoy may be taking, and also along the periphery of the convoy

movement while data is collected for Improvised Explosive Device (IED) detection. Another critical tactical mission-environmental intersection is with regard to Chemical, Biological, Radiological and Nuclear (CBRN) threats where the threats are characterized by irregular plumes whose kinematics are affected by localized weather conditions. Multi-UAV ISR coverage optimized for the environmental conditions may be extremely helpful to the safe execution of USMC mission activities in these environments.

A follow-on project will transition the COAMPS-OS/Nowcast environmental data fusion, data assimilation, forecast, and nowcast technology within a dedicated system to support USMC operations in Iraq and Afghanistan. Some specific technological advances that are not in the current operational systems but, when implemented, would make the existing systems more net-centric enabled, for example, Net-Centric Enterprise Services (NCES) compliant EVIS system integrated with a GIS standards-based Web Mapping Server (WMS) and IMETS data/products available through web services, should be accomplished through a dedicated effort to provide environmental mission impact parameters through a family of geospatial information web services. The system should be implemented on the SIPRNET at FNMOC, Monterey, CA, in net-centric reach-back mode. The developers should work directly with the USMC user to tailor the products and services to their mission needs and Command and Control applications, for example C2PC and GCCS-M/JC2, while using their available sensor data, including data derived from through-the-sensor technology to extract the environmental signal from tactical sensor data (e.g., radars, autonomous vehicles, forward air controllers). Furthermore, NRL can partner with ARL to transition selected software components of their existing environmental modeling, data fusion, and product development technology supporting ground combat operations in order to leverage the DOD investment for the USMC. In transitioning the capability, we envision that additional software will need to be developed to integrate the Army's and Navy's technologies to provide a common environmental representation in a secure, standards-based, net-centric, reach-back framework.

Data fusion and extrapolation are two major techniques exploited in the Nowcast system. They are currently widely used in the nowcast community due partially to the limited performance of NWP models during the first few hours of model integration, mainly caused by model initialization. The traditional extrapolation technique, however, has its limits in nowcasting high-impact weather conditions. First, because of the nonlinear nature of severe weather, its performance beyond two hours is poor. Second, its predictive capability is limited because development is not handled correctly. Now, most customers, especially the warfighters, require a nowcasting time window of 0 - 6 hours and prediction of both severe and non-severe weather events (such as heavy fog, low visibility, strong low-level inversion, etc). So in long term, high-resolution NWP modeling is the desired approach for nowcasting. Currently, NRL is working toward assimilating tactical-scale sensor data into the high-resolution COAMPS model to improve the capability and accuracy in predicting high-impact weather during the 0 – 6 hour nowcasting time window.

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7. Appendix A - Top Level Design Document for the NRL Nowcast for the Next Generation Navy System

7.1 Scope

7.1.1 Identification

This Top Level Design Document describes the requirements for the Naval Research Laboratory (NRL) Nowcast for the Next Generation Navy (NOWCAST) system. NOWCAST is an enterprise-class, network-centric, data fusion concept which will allow the forward-deployed battlegroup forces and other networked locations to continuously update a local, centralized environmental database and send fused products to end user client tactical workstations. NOWCAST will enable the automatic maintenance of a common picture of the three-dimensional environmental battlespace among the battlegroup components and other networked locations, and will provide products to end users tailored to their specific warfighting requirements. NOWCAST will be submitted as a set of application segments in the Defense Information Infrastructure (DII) Common Operating Environment (COE) and also as a stand-alone client/server application for non-DII/COE systems. This document also describes the background, required functionality, and constraints for developing the NOWCAST system.

7.1.2 System Overview

NOWCAST will be an automated, portable, environmental data fusion and web-based data dissemination and display system for the battlegroup and other regional enterprises (e.g., a Navy or Joint METOC Facility). As an enterprise-class solution, NOWCAST is designed to provide the best environmental information to end users to support informed, integrated decision making. NOWCAST is an observation-oriented, network-centric, data fusion concept in which a local, centralized, real-time environmental database is frequently updated to generate fused products that are automatically and continuously transmitted back to configurable end user terminals, thus maintaining a common situational awareness of the three-dimensional environmental battlespace. NOWCAST will allow the forward-deployed METOC user to add significant value to the volume of raw, perishable atmospheric data available on-scene by intelligently fusing the information with locally-derived mesoscale model background fields. Feature detection and tracking algorithms can make use of high temporal rate data to extrapolate features (e.g., gust fronts and precipitation areas) into the near-term (0 – 2 hrs). Artificial intelligence (AI) techniques may be used to blend the extrapolated results with fields produced from a mesoscale model to extend the forecasts to 6 hrs. This is important because the spin-up time of the mesoscale model is on the order of 2 – 6 hrs, thus NOWCAST fills the gap at the beginning of each data assimilation cycle.

NOWCAST servers will reside on the battlegroup and shore-based METOC local area networks (LAN) along with the Tactical Atmospheric Modeling System – Real Time (TAMS-RT). On board ship, the On-Scene Tactical Atmospheric Forecast Capability (STAFC), a software component of the Navy Integrated Tactical Environmental System (NITES), will provide the functionality of TAMS-RT. TAMS-RT/STAFC will produce the local short-term mesoscale forecasts and hourly analyses that will be used as

background conditions for NOWCAST. These fields will reside in the Tactical Environmental Data Subsystem (TEDS) servers and will be retrieved by NOWCAST using the TEDS Application Programming Interfaces (API) once every hour. TEDS is also the repository for almost all other environmental data shared by the battlegroup and regional enterprises. The latest data, which may contain decoded ASCII messages, decoded World Meteorological Organization (WMO) Gridded Binary (GRIB) and Binary Universal Format (BUFR) messages, and other remotely-sensed observations, will be retrieved by NOWCAST using the TEDS APIs periodically (probably every 5 – 20 min) depending on the data type. A separate flat file database of battlegroup radar observations will also be retrieved (possibly every 5 min). These radar data will have been preprocessed locally by the Tactical Environmental Processor (TEP) aboard AEGIS SPY-1 equipped ships within the battlegroup and transmitted to the TEDS servers. The TEP will also provide local wind shear and microburst processing once every minute. If significant wind shear is detected, an alert and the location shall be transmitted to the NOWCAST server for immediate dissemination to end users.

Figure A-1 is a schematic diagram of the NOWCAST system components and data flow showing the interaction with the TEDS and TAMS-RT/STAFC components. The client/server design for NOWCAST is also shown in the figure. The NOWCAST server is an extension of a traditional web server using Java Servlet technology and Java Server Pages for automatically refreshing dynamic content. The clients are Java applets that can be activated from any end user web browser on the network. Once running, the clients will be updated with the latest available data at any given time by automatically refreshing every five minutes. The clients are designed using the concept of data layers (or overlays), where each layer is geographically registered to a user-defined map background. The data layers are defined in Section 7.2.9. The map may be panned and zoomed with the mouse for viewing a more specific region of interest and a time slide will be provided to control the time looping. The default loop will cover the past two hours in five-minute increments.

The layered client application is shown schematically in Figure A-2 and is described in more detail in Section 7.2.7. The user may select data layers for viewing and may bring up a properties screen where graphics and other data attributes may be set to customize the display for the user. A click on a position will bring up a properties window showing the closest observation (in space and time) and a double click will bring up a time series for that location covering the past 24 hrs. For any data product, the corresponding background mesoscale model field can be toggled on and off.

In addition to METOC data layers, fused data products (defined in Section 7.2.10) derived from algorithms using the observed data and model fields as inputs, may also be toggled on and off the display. Multiple data products that provide information related to a common task or warfare area may be grouped or bundled together by the end user into a named product folder. These product folders may be saved on the server and recalled for editing. Examples of product folders are shown in Figure A-2. All data, fused data, and product folders recalled from the server will dynamically refresh with the latest available data at the five minute update rate. All user configurations are saved on the NOWCAST

server and protected by user names and passwords. The NOWCAST server provides administration support tools for the METOC user to manage the user accounts and profiles (see Section 7.2.17).

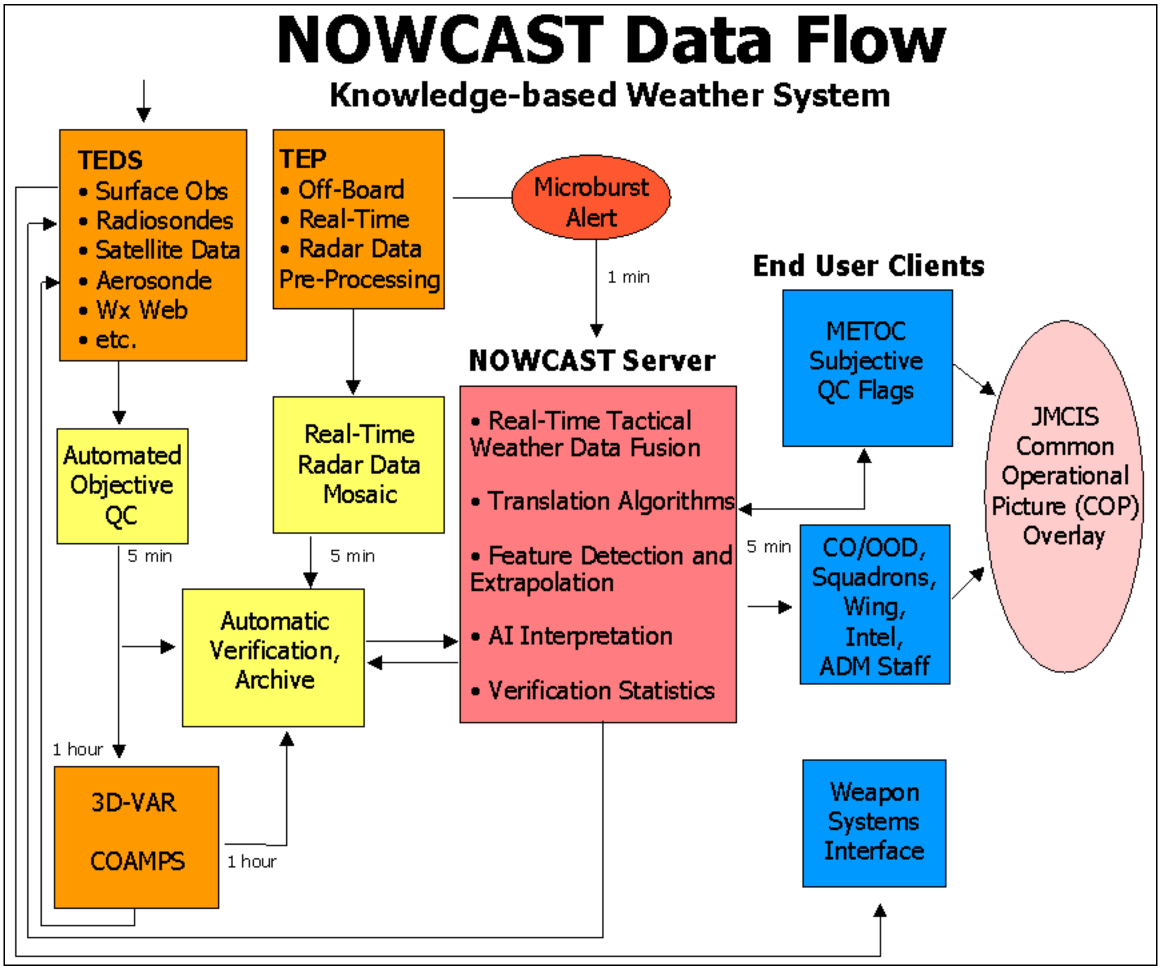

Figure A-1. NOWCAST data flow.

To facilitate administration and to maintain quality control, NOWCAST provides a special client for the METOC user. This client automatically displays all the data types (overlays) by default and has special privileges to let the METOC user perform quality control (QC) functions and tag “bad” data, sensors, and stations and model output. Bad data tags shall be recorded in the database and the system will not use the data, sensor, station, or model output nor transmit them to end users until the METOC user toggles the QC flag back to “good.”

Both METOC and end users will be able to set visual and audio alerts for their data. User-defined thresholds and QC values (comparison with background fields, previous observation, or buddy check) shall also be provided. An automatic alert (not user configurable) will be provided for the radar wind shear message.

An Internet Relay Chat (IRC) button on the main Java applet will allow an IRC session to be spawned by the user. The default behavior will be to initiate a chat session with the responsible METOC office, although the chats may have several participants at one time. It is anticipated that these IRC sessions will be used to interact with the on-scene METOC specialists about critical data and interpretation of products. Since everyone in the NOWCAST system "sees" the same environmental data, the METOC specialists and the end users can chat and relate to a common visualization of the data and products. The collaboration supported in the initial NOWCAST system will be limited to the IRC sessions, however, future enhancements to NOWCAST will allow the graphics windows to be a shared whiteboard, allowing truly collaborative data and product visualization and discussion to facilitate tactical understanding.

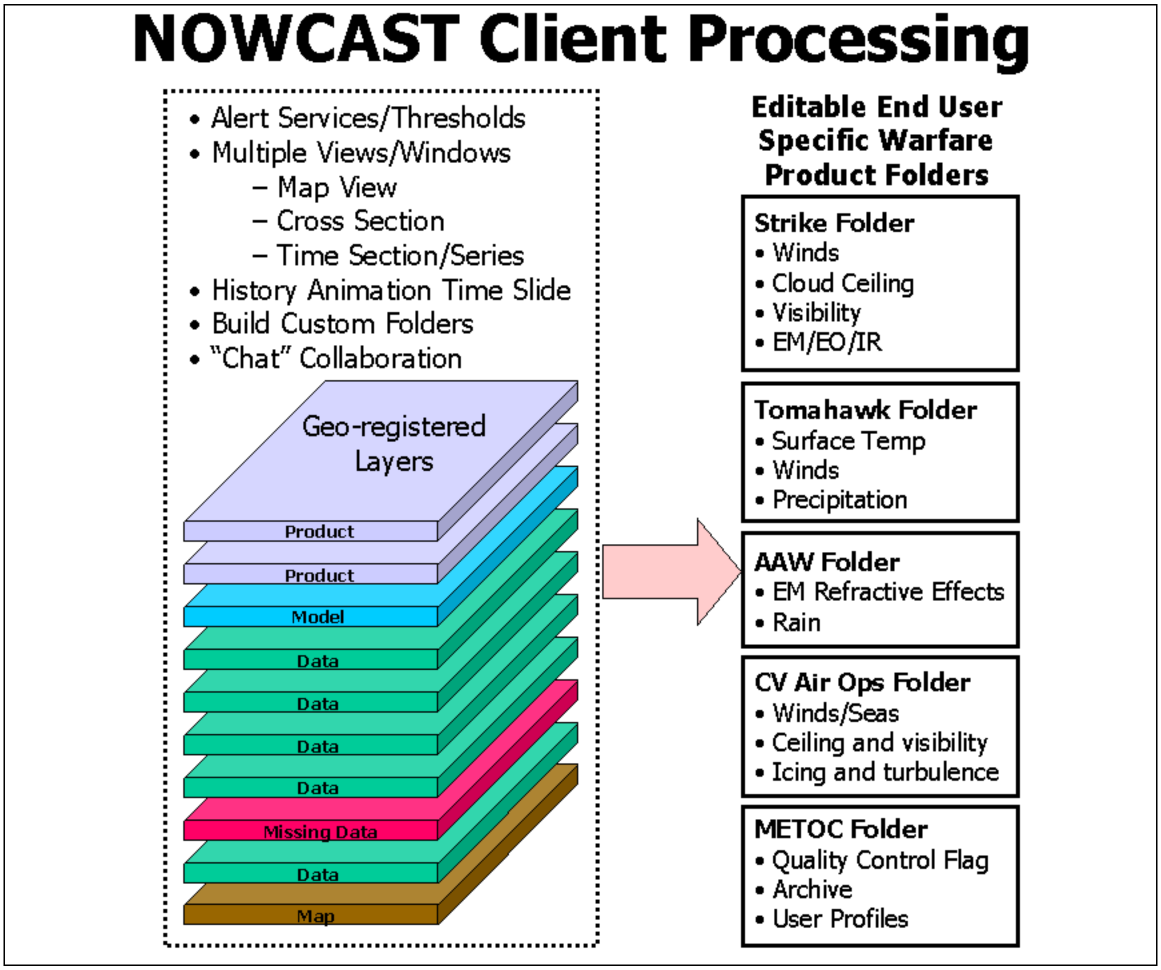

Figure A-2. NOWCAST client processing.

7.1.3 Background

The complexity of the battlespace necessitates the automated fusion of environmental information with the tactical picture to maintain common situational awareness. The battlegroup of today has no capability to efficiently share environmental information among its components or to maintain a consistent picture of the battlespace environment. However, advances in forward-deployed sensing systems present an opportunity to the

METOC community to overcome this limitation. Systems such as MORIAH, MEASURE, AEROSONDE, Remote Mini Weather Stations (RMWS), TEP (for radar data), TDROP tactical dropsonde, and the Navy Satellite Display System – Enhanced (NSDS-E) (high refresh rate geostationary satellite data) are in various stages of development and fielding. None of these sensors or systems alone presents the full environmental picture; however, work at the National Center for Atmospheric Research (NCAR) and at the Massachusetts Institute of Technology Lincoln Laboratory (MIT LL) has demonstrated how artificial intelligence techniques, including fuzzy logic, may be used to fuse these types of sensor data into a coherent, consistent view of the constantly evolving local environment. Other algorithms developed at NCAR and MIT LL have been used to identify significant meteorological features and track them using automated techniques. These tracking techniques allow the features to be extrapolated into the near-term future (1 to 2 hrs) for short range forecasts or "nowcasts." These data-derived nowcasts can be combined with analyses and short-term mesoscale model forecasts produced by the local TAMS-RT to extend the range from 2 to 6 hrs. This fused picture of the environment can be updated continuously and propagated (served) from a main processor to customized end user terminals using web-based client/server technology. Such a nowcast system, built on the DII/COE compliant base architecture, will give the battlegroup and navy shore activities a new capability to effectively provide integrated, accurate, real-time, consistent, useful environmental information tailored to the individual needs of the warfighter.

The concept described above is articulated in the Oceanographer of the Navy's (N096) Rapid Environmental Assessment (REA) program goals (Whitman, 1997). The development of the TAMS-RT/STAFC on-scene mesoscale forecasting capability was the first step in achieving those goals and NOWCAST will provide the necessary follow-on capability. On-scene mesoscale forecasting and NOWCAST are the focused end of a telescoping strategy developed by NRL to meet REA requirements. The "big picture" end of the strategy is anchored by the NRL Navy Operational Global Atmospheric Prediction System (NOGAPS) (Hogan and Rosmond, 1991) which provides a world-class global prediction capability out to 10 days. The NRL Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) (Hodur, 1997) provides shorter range, higher resolution forecasts and forms the core of TAMS-RT/STAFC. Both NOGAPS and COAMPS are run operationally at Fleet Numerical Meteorology and Oceanography Center (FNMOC), Monterey, CA. COAMPS is a state-of-the-art nonhydrostatic mesoscale model that has been used to study atmospheric structures from 81 km down to 1/3 km resolution. COAMPS is also used in TAMS-RT/STAFC for limited geographic domains and both NOGAPS and COAMPS may be transmitted by FNMOC to provide boundary conditions for the on-scene mesoscale forecasts. These fields are transmitted from FNMOC to fleet units using the METCAST data dissemination capability.

Early in the NOWCAST system development, two high priority areas for initial system support were identified: the operational tasks of carrier air operations and electromagnetic (EM) propagation assessment. Subsequently, strike warfare (STW) issues were also identified for support. Both carrier air operations and STW rely heavily on ceiling and visibility (C&V) assessments; in fact, operational forecasters spend about

40% of their time developing such guidance. Therefore, a C&V product was identified as a desirable fused-technology product. Interactions with NCAR and MIT LL have identified other mature technologies such as Autonowcaster, Intelligent Weather System (IWS), Machine Intelligent Gust Front Algorithm (MIGFA), optimal trajectories, line storm tracker, microburst detection, anomalous propagation (AP) rejection, as well as fused-technology products such as icing, turbulence, thunderstorm information, cloud classification, and rain rate which would make valuable additions to the NOWCAST product suite. Many of the more mature capabilities that are required for NOWCAST are described in Section 7.2.10.

NOWCAST follows the current direction in the Navy by embracing an enterprise-wide, network-centric, web-based client/server design. The NOWCAST server will automatically ingest and fuse data, derive data products, update the TEDS database, and propagate the fused data set to each client workstation, thus maintaining a common picture of the environment from the warfighter to the decision maker. NOWCAST is envisioned to be the enterprise weather fused data product server for the battlegroup and, as a critical enterprise server capability, NOWCAST is designed as a multi-tiered solution with automatic fail-over capability, transparent to the operator.

7.2 Requirements

7.2.1 Fleet METOC Requirements

- METOC Requirement 94-08 – Real-Time Tactical METOC Assessment System
- METOC Requirement 95-02 – Sensible Weather Forecasting Tool
- METOC Requirement 95-05 – State-of-the-Art Display/Briefing System
- METOC Requirement 96-08 – Real-Time Data Collection Capabilities
- METOC Requirement 97-05 – Consolidation and Quality Control of METOC Data
- METOC Requirement 97-08 – Numerical Modeling for Military Operations

7.2.2 Mission Needs Statements

- Real-Time Tactical METOC Assessment System
- METOC On-Scene Analysis and Forecast Capability
- METOC Numerical Modeling Capability for Military Operations

7.2.3 Oceanographer of the Navy (N096) Program Support Needs

- Rapid Environmental Assessment
- Sensing the Battlespace Environment
- Assimilation of Diverse METOC Data

7.2.4 NRL Battlespace Environments S&T Challenges

- Data/Information Management and Exploitation (IE)

7.2.5 Capability Requirements

NOWCAST shall be capable of the following functions, each described in more detail in subsequent subsections below:

- Provide an enterprise-wide weather data and fused products server to allow end user client workstations to automatically receive updated information as soon as the data have been processed and fused. Automatically fail-over to provide continuous coverage for critical products.

- Access and assimilate observational data, gridded fields, and satellite data from the TEDS database in real-time. Access, mosaic and assimilate radar data in real-time. Immediately transmit wind shear alerts.

- Provide a configurable tactical end user workstation client application to view, animate, manipulate, threshold, zoom, pan, print, bundle, and set alerts for the NOWCAST server data stream.

- Provide a configurable METOC client workstation that, in addition to the above-stated tactical workstation functionality, provides a means to set quality control flags for the data.

- Provide an interface to store NOWCAST output data products and quality control flags in TEDS.

- Provide administrative tools to set up and maintain NOWCAST servers and clients and provide an archive capability to save data and products. Provide tools to manage user accounts and profiles.

- Provide an auto-verification capability to maintain a historical database of observations, forecasts/nowcasts, and the differences between the observations and the forecasts/nowcasts.

7.2.6 NOWCAST Server Requirements

The NOWCAST server will reside on the battlegroup and shore-based METOC LAN along with TAMS-RT/STAFC. Figure A-3 is a schematic showing the NOWCAST server high-level architecture and data processing design. TAMS-RT/STAFC will produce the local short-term mesoscale forecasts and analyses that will be used as background conditions for NOWCAST. These forecast fields will reside in the local TEDS database servers and will be retrieved by the NOWCAST server using the TEDS APIs once every hour. The latest decoded ASCII message data, decoded GRIB and BUFR data, and other remotely-sensed observations, will be retrieved by the NOWCAST server every 5 – 20 min depending on the data type. A separate flat file database of preprocessed battlegroup radar observations will also be retrieved, probably every five minutes. Data from multiple radars will be consolidated in a mosaic if required. All data will be registered to the same map projection and background (as specified in the set up by the METOC user) as interest fields. The server will execute all identification, processing, and tracking algorithms on the data included cloud classification, line storm tracking, autonowcaster, MIGFA, turbulence, icing, EM propagation/evaporation duct height, AP rejection, surface heat index, and 3-D wind finding. AI and fuzzy logic techniques will be used in some algorithms to update the Intelligent Weather System

(IWS) products. These techniques may make use of dynamic weighting to give greater emphasis to algorithms with better current verification statistics in the blending scheme.

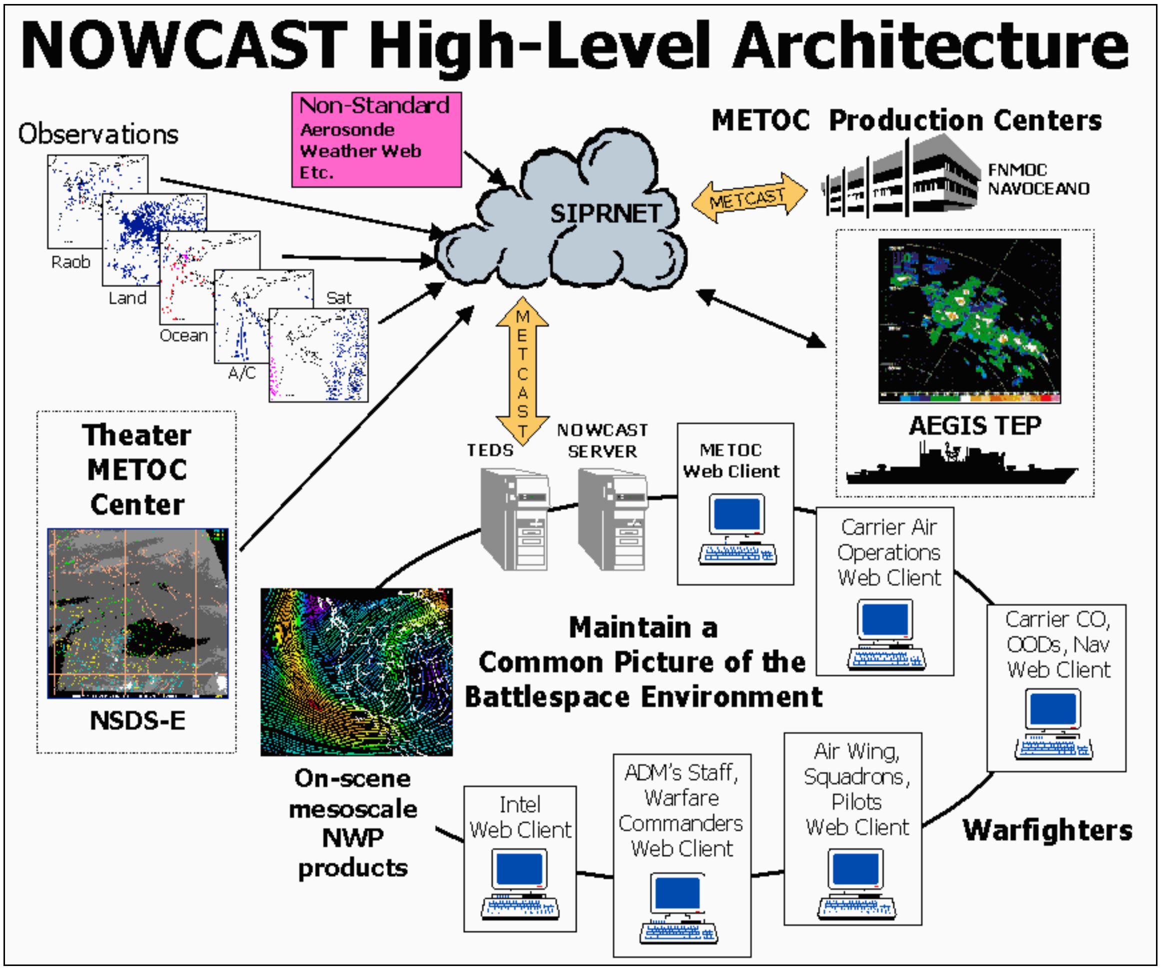

Figure A-3. NOWCAST high-level architecture.

All appropriate data will be automatically compared with the previous corresponding interest fields and forecasts for the purpose of automatic verification. Time series of the data and their differences will be recorded and maintained along with the computed statistics for mean error and bias. The verification information will propagate through the NOWCAST system with the interest fields to give the end user some information about the quality or confidence of each product.

The NOWCAST server must also provide user login and authentication (password) services and set the user's run-time environment. The server shall maintain a common run-time information database that can be queried to return all user and data parameter specifications. Section 7.2.17 describes the maintenance and administration capabilities of the server.

7.2.7 NOWCAST Client Requirements (Tactical End user)

NOWCAST clients are Java applets that can be activated from any end user browser on the network. Figure A-4 is a mock-up of a client display showing radar, precipitation, station temperature and wind, and icing cross section information. Once activated in the browser, the clients refresh automatically at the five-minute NOWCAST data retrieval interval. The clients are built based on the concept of data layers (or overlays), where each layer is represented by a tab or button across the top window and the layers are geo-registered to a user-defined map background. The layers represent data types, model data, and derived NOWCAST products. Each layer may be toggled on and off with the mouse. The area the map covers must be a subset of the master map defined by the METOC user (typically they are covered by the largest mesoscale model grid). Map functions will be configured by a popup GUI which will control land/sea boundaries (coastlines), shaded topography, political boundaries, and major cities and roads, which can all be toggled on or off. In addition, the user shall be able to define hazardous bounding areas (airspace) and waypoints which can act as pseudo-stations for the purpose of plotting data and interpreting results. The map may be panned and zoomed with the mouse for specific regions of interest and a time slide and clock will be provided to control the time looping. The default loop will cover the past two hours in five-minute increments. The latitude/longitude position of the mouse within the map display will be displayed at all times following the mouse.

In addition to the mouse functionality described above, the user may select data layers to be turned on (brought to the foreground) or off by clicking on the appropriate tab. The user may also click the tab with the right mouse button to bring up a graphics properties screen where semi-transparency and all other graphics properties may be set so the underlying map and data can be viewed more easily once the data are rendered. The properties of the data that may be manipulated by the end user client application are:

- Plot color
- Line thickness
- Line type
- Font
- Contour interval
- Contour origin
- Contour levels
- Scale
- Color shading
- Wind vector/barb
- Units
- Thresholds
- Alarms

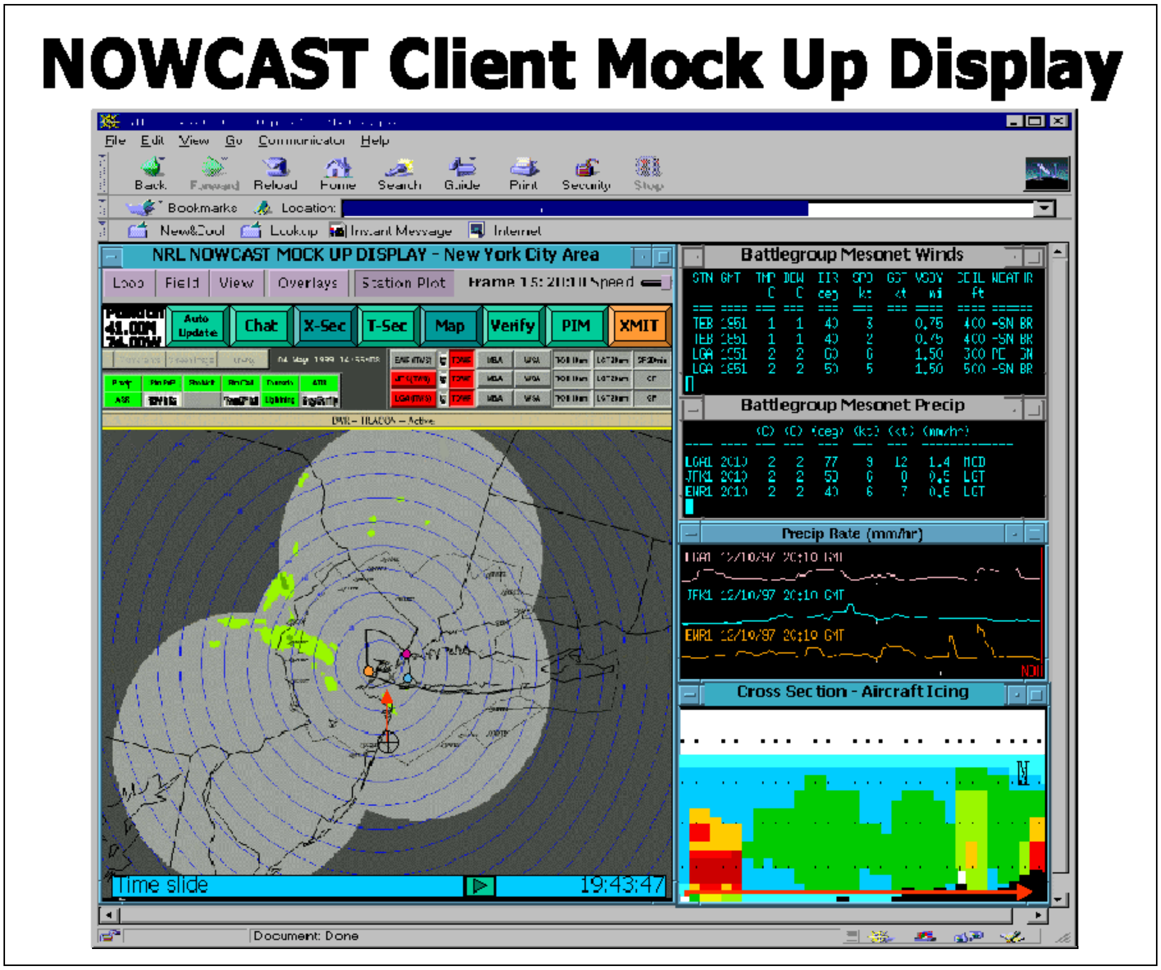

Figure A-4. NOWCAST client mock up display.

A mouse click on a location within the map will bring up a properties window showing the closest observation (in space and time) or model-derived pseudo-observation (all parameters) in an ACSII format (surface type observations). A double click on a location will automatically submit a request to the server for a time series plot product of the data for the past 24 hrs. The time series windows will contain toggle buttons for the various parameters and a time slide to query the data at a particular time defined by the mouse pointer location. For profile observations, the mouse click on a point will designate a location and submit a server request for a pop up graphics window with the observation rendered inside it as a scaled plot. For products like the profile display that have a vertical extent, a slider will be provided to select the flight altitude for display. The profile time series will consist of an animation of the profiles for the last 24 hrs controlled by a mouse time slide. For any product, the corresponding background mesoscale model forecast field can be toggled on and off with the keyboard or mouse.

Cross sections and time sections shall also be supported in the client. To set up a cross section, the user should define a path of two or more way points using the mouse or a type in dialogue box (for the precise latitudes and longitudes in degrees, minutes, and seconds format) and then click the submit button to send the product request to the server.

The cross section time series will consist of an animation of cross sections for the past 24 hrs controlled by a mouse time slide. For time sections, a point and altitude range shall be selected and submitted to the server in a manner similar to the cross section.

Fused data products defined in Section 7.2.10 may also be toggled on and off by clicking on their tabs. Multiple data products may be selected and deselected by holding down the shift key while clicking the desired tabs. Folders consisting of a group of multiple products may be bundled and saved under a unique name from the file menu and may also be read in, edited and then saved, overwriting the file of the same name, or saved as another name. All user configurations are saved on the NOWCAST server which also saves the associated user names and passwords and provides the administration support tools described in Section 7.2.17 to manage the user profiles.

The user of a NOWCAST client shall also be able to set visual and audio alerts for their data and products using the alt key in conjunction with clicking on the appropriate tab. User-defined thresholds and QC values (comparison with background fields, previous observation, or buddy check) may be enabled and disabled from this popup menu. Both visual alerts (lighted or blinking tabs) and audio alarms should be supported.

The NOWCAST client should also be capable of reading a file containing the ship's point of intended movement (PIM) or other time-based geographic references in order to "follow along" automatically. This option should be available to automatically and continuously keep the map display or profile centered on a particular location.

An Internet Relay Chat (IRC) button on the client will allow an IRC session to be spawned by the user. The default behavior will be to initiate a chat session with the responsible METOC office; it is anticipated that these IRC sessions will be used to interact with the on-scene METOC specialists about critical data and interpretation of products. Since everyone in the NOWCAST system "sees" the same picture of the environment, the METOC specialists and the end user can chat and relate to a common visualization of the data and products. A future enhancement to NOWCAST will be to make the graphics windows a shared whiteboard allowing truly collaborative data and product visualization and discussion to facilitate tactical understanding.

7.2.8 NOWCAST Client Requirements (METOC End user)

In addition to the functionality described above for the tactical client, the NOWCAST system also contains a special METOC client which automatically displays all the data types (overlays) by default. This client has special privileges to let the METOC user quality control (QC) and tag "bad" data, stations, or model products. Bad data tags shall be recorded in the data base and the system shall not use the data in derived applications nor display it to end users. The tagged data should be displayed on the METOC client with a highlighted ring or border around the station location or product. The data stream or product from a particular sensor shall remain tagged until the METOC user toggles the QC flag back to "good". The QC flag will be enabled from the observation or product popup properties window.

The METOC client shall also have the ability to set up the master NOWCAST background map that will define the maximum spatial extent of the products. The map server will have a separate pop up menu dialog system to control all aspects of the map including projection, shore line and political boundaries, topography, and cities. Land use characteristics may also be included in the underlying map. System administration tools for the METOC client to manage user accounts, passwords, and access are described in Section 7.2.17

7.2.9 Data Requirements

The following data types will be processed and displayed on the NOWCAST client:

- Air Temperature (°C and °F)
- Air Dewpoint Temperature (°C and °F)
- Relative Humidity (%)
- Height (m and ft) of a Pressure Level (mb)
- Sea Level Pressure (mb)
- Altimeter Setting (in of Hg)
- Winds (barbs or vectors in m/s or kts) at user-specified flight levels (m or ft)
- Rain Rate (tenths of an inch or mm/hr)
- Radar Reflectivity (dBZ)
- Terrain Height (m or ft)
- COAMPS Land Use Category (94 categories)

7.2.10 Product Requirements

The following products will be derived from algorithms using the observed data and model generated fields as input:

- Thunderstorm Autonowcaster
- Thunderstorm Line Tracker
- Icing (Frost, Rime, Clear)
- Turbulence Category (Severe, Moderate, Light)
- Wind Shear
- Visibility (km or mi)
- Cloud Fraction (eighths or tenths)
- Cloud Ceiling (m or ft)
- Cloud Base (m or ft)
- Cloud Top (m or ft)
- Cloud Type (11 cloud classifications)
- EM Duct Height (m or ft)
- Modified Refractivity (m-units)
- Optimal Trajectory
- Surface Heat Index (°C or °F)
- Gust Front Tracker (MIGFA)
- Microburst Identifier
- Illumination (lumens)
- AP Rejection Map

7.2.11 AutoVerification Requirements

The NOWCAST system shall have an automated verification software package to 1) maintain statistics on the behavior of observations from sensors (running mean, etc.); 2) maintain current statistics of how well each sensor output compares to background or first-guess fields and derived interest fields (mean error, bias, etc.); 3) maintain current statistics of how well each derived product compares to observations (mean error, bias, etc.). The errors shall be stored in a local database and the clients shall have the capability to display the current statistics along with the observed data (point location, area contour map, and shaded map). The verification data shall also be included in the NOWCAST system archive for further off-site analysis.

7.2.12 External Interface Requirements

NOWCAST will support the following external interfaces:

- A network interface using standard TCP/IP and HTTP protocols for communications with TEDS, the radar data flat files, and client workstations.
- Interfaces to TEDS to retrieve data required as inputs and to store data output. These interfaces will be via the TEDS APIs.
- An external interface shall also exist to archive data to tape.
- NOWCAST clients shall be able to export overlays to the Common Operational Picture (COP) in Rainform Gold format.

7.2.13 Internal Interface Requirements

The internal interfaces are the Java client applet/server connections that rely on the TCP/IP/HTTP network link.

7.2.14 Computer Hardware Requirements

The NOWCAST server will be a multiprocessor personal computer including four processors, 1 GB memory, CD-ROM, dual 10/100 Mbit/sec network controllers, 54 GB internal SCSI disk, 4 mm DDS3 tape drive, dual power supplies, and will operate either the Windows NT or SolarisX86 operating system. The system shall operate on standard 110V US power and be connected to an uninterruptible power supply (UPS).

The NOWCAST clients will be Java applets available from any Netscape or Microsoft Explorer browser on the network.

7.2.15 Computer Software Requirements

The NOWCAST server operating system will be either Windows NT or SolarisX86 and the programming languages will be C, C++, Java, and FORTRAN 90. NOWCAST will also support Perl, JavaScript, and Tcl/Tk scripting. NOWCAST will use a public domain database for storing user authentication and user profile information.

7.2.16 Communications Requirements

NOWCAST shall support the Navy IT-21 networking standards with 10/100 mbit/sec network controllers using standard TCP/IP internet transmission protocols.

7.2.17 Maintainability Requirements

The NOWCAST METOC client shall have additional menus that allow maintenance of user accounts, passwords, and user profiles in the system. The menus shall also control the data archive, purge, and initial load capabilities as well as control the various GUIs for the derived products programs.

NOWCAST will be maintainable to the extent possible from the code, program definition language, and documentation, in that order. The software shall be documented according to the standards set forth in MIL-STD-498 and/or the DII/COE documentation requirements.

Acronyms

AI	Artificial Intelligence
AP	Anomalous Propagation
API	Application Program Interface
BUFR	Binary Universal Format
C&V	Ceiling and Visibility
COAMPS	Coupled Ocean/Atmosphere Mesoscale Prediction System
COP	Common Operational Picture
DII/COE	Defense Information Infrastructure/Common Operating Environment
EM	Electromagnetic
FNMOC	Fleet Numerical Meteorology and Oceanography Center
GRIB	Gridded Binary
GUI	Graphical User Interface
IRC	Internet Relay Chat
IWS	Intelligent Weather System
LAN	Local Area Network
METOC	Meteorology and Oceanography
MIGFA	Machine Intelligent Gust Front Algorithm
MIT LL	Massachusetts Institute of Technology Lincoln Laboratory
NCAR	National Center for Atmospheric Research
NITES	Navy Integrated Tactical Environmental System
NOGAPS	Navy Operational Global Atmospheric Prediction System
NRL	Naval Research Laboratory
NSDS-E	Navy Satellite Display System – Enhanced
PIM	Point of Intended Movement
REA	Rapid Environmental Assessment
RMWS	Remote Mini Weather Station
STAFC	On-Scene Tactical Atmospheric Forecast Capability
TAMS-RT	Tactical Atmospheric Modeling System – Real Time
TEDS	Tactical Environmental Data Server
TEP	Tactical Environmental Processor
UPS	Uninterruptible Power Supply
WMO	World Meteorological Organization

References

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